



ASIA EDITION

Vol. 7 Issue 6

Knowledge

SCIENCE • HISTORY • NATURE • FOR THE CURIOUS MIND

INCORPORATING

SCIENCE
WORLD

Discover the

UNIVERSE NEXT DOOR

...where time runs backwards p24

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TV Channel



A Cabbie Abroad

Premieres 17th June. Wednesdays at 8.55pm (JKT/BKK), 9.55pm (SIN/HK/MAL/TWN)

London cab driver Mason McQueen – known from the acclaimed documentary series *The Toughest Place to Be* – spends time living and working with local taxi drivers to experience their lives and find out about the wider issues facing their countries and communities.



Extreme Fishing with Robson Green

Starting from 17th June,
Wednesdays at 9.40pm (JKT/BKK),
10.40pm (SIN/HK/MAL/TWN)

Robson Green is taking extreme fishing to a different level to outwit the weirdest, the most aggressive, and the hardest to catch fish ever.



Deadly Pole to Pole

New episodes from 18th June.
Thursdays at 8.00pm (JKT/BKK),
9.00pm (SIN/HK/MAL/TWN)

Join Steve Backshall and his trusty crew on an epic journey - from the Arctic to the Antarctic in search of some of the deadliest animals on earth.



Ross Kemp – Extreme World S4

Fridays at 9.40pm (JKT/BKK),
10.40pm (SIN/HK/MAL/TWN)

In this new series, Ross travels from the frontlines of the war in Ukraine to the underworld of Australian biker gangs and even to his own dying coastal towns, gaining access to the some of the extraordinary places in the world.



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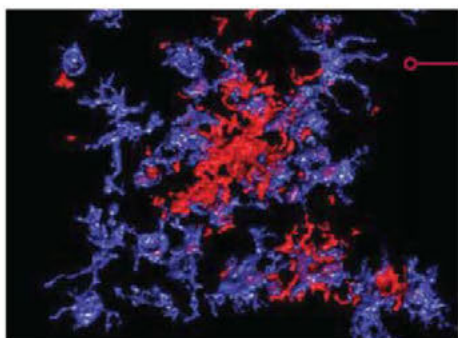
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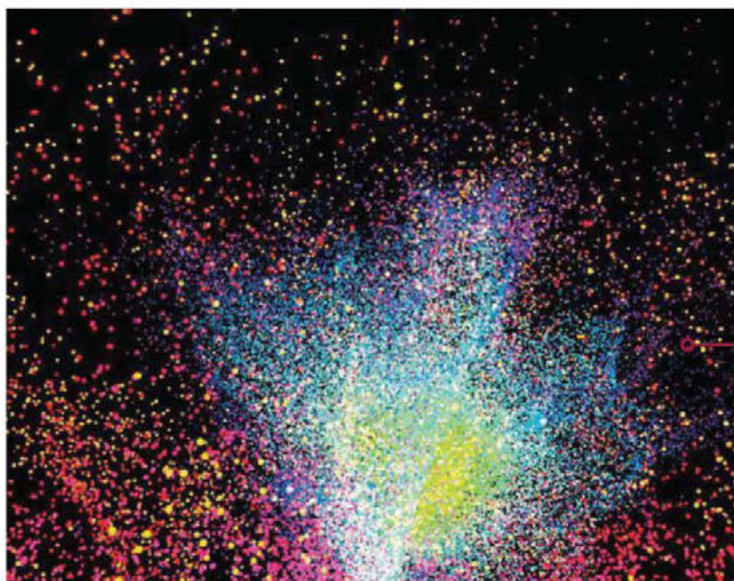
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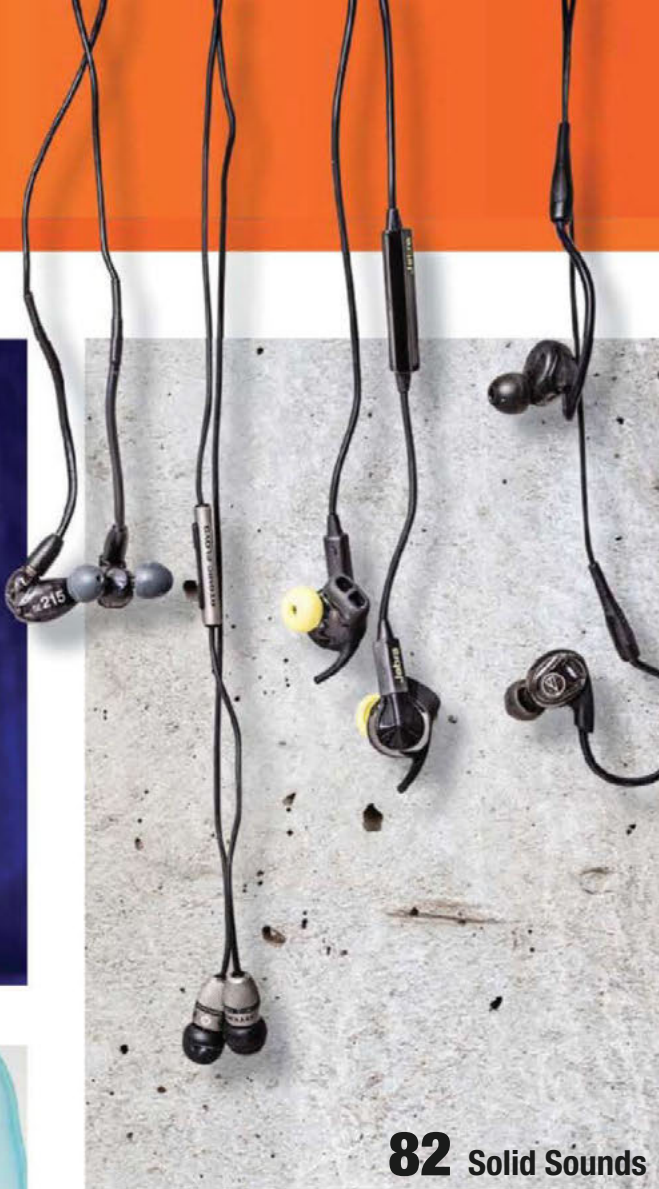
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WHERE TIME RUNS BACKWARDS

Looking at my daughters running amok in the playground got me thinking, and about time for some bizarre reason and how or why it governs our everyday lives.

We humans have devised different units to measure it, the seconds, minutes, hours, as well as years, decades, centuries, millennia and so on, for the passing of time. The different seasons, the rising and setting of the sun, the moon phases, the ebb and flow of the tides have all been inferred by us as nature's way to mark the passing of time as well, but why do we think that time only moves in a directional manner?

The fundamental laws of physics allow processes to function perfectly regardless of the direction they are going, so why is time any

different? Can we have a universe that co-exists with ours but time works in reversal? Although it is true we never see the pieces of a broken mug jump back together or people getting younger instead of older, however if we assume all possibilities are likely, these scenarios are highly probable but to be able to witness such a phenomenon, we probably have to wait many millennia or longer.

Ben Poon
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Experts in this issue...



Marcus Chown

Award-winning science writer and author Marcus talks about a new theory of time that could solve some of the biggest problems in physics. Turn to p24 to discover more.



Colin Stuart

Astronomer Colin is also co-author of *The Big Questions In Science*. On p34, he finds out what the Dawn mission to Ceres will teach us about the Solar System's origins.



Hayley Birch

Science writer Hayley is co-author of *The Big Questions In Science*. On p40, she takes a closer look at the plastic floating in our oceans and finds out what's lurking beneath the surface.



Jon Butterworth

Jon is a physics professor at University College London and works on CERN's Atlas experiment. On p52 he tells us what scientists hope to find when the LHC is switched back on.



Knowledge

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Snapshot



Flying high

Resembling a clutch of giant eggs, Britain's latest helium-filled airship, Airlander 10, sits in a cavernous hangar at RAF Cardington. Despite being the world's longest aircraft at 92m (302ft) in length, the vessel is surprisingly agile. It is able to take off and land from any flat surface, including water, sand and ice, and can carry loads exceeding 10 tonnes. It can attain speeds of 110-130km/h (68-81mph).

"It flies and floats like an airship, its unique hull shape creates aerodynamic lift like an aeroplane, and its engines can rotate and push air out at any angle, allowing it to hover and be controlled like a helicopter," explains Chris Daniels at Hybrid Air Vehicles, the company responsible for its design. "This makes it an exceptionally efficient and versatile aircraft, with endurance measured in weeks, rather than days."

It could potentially be used for search-and-rescue missions, luxury cruises, or carrying freight to remote locations such as oil rigs, the company says. Test flights are scheduled for later this year.

PHOTO: GETTY

Psychedelic stinger

This tangle of pastel-hued coils belongs to a Portuguese man-of-war. Despite resembling a jellyfish, it is actually a compound organism called a siphonophore. A gas-filled sac, a pneumatophore, floats on the ocean's surface. Three types of polyp create a drifting veil of tentacles that stretches for up to 50m.

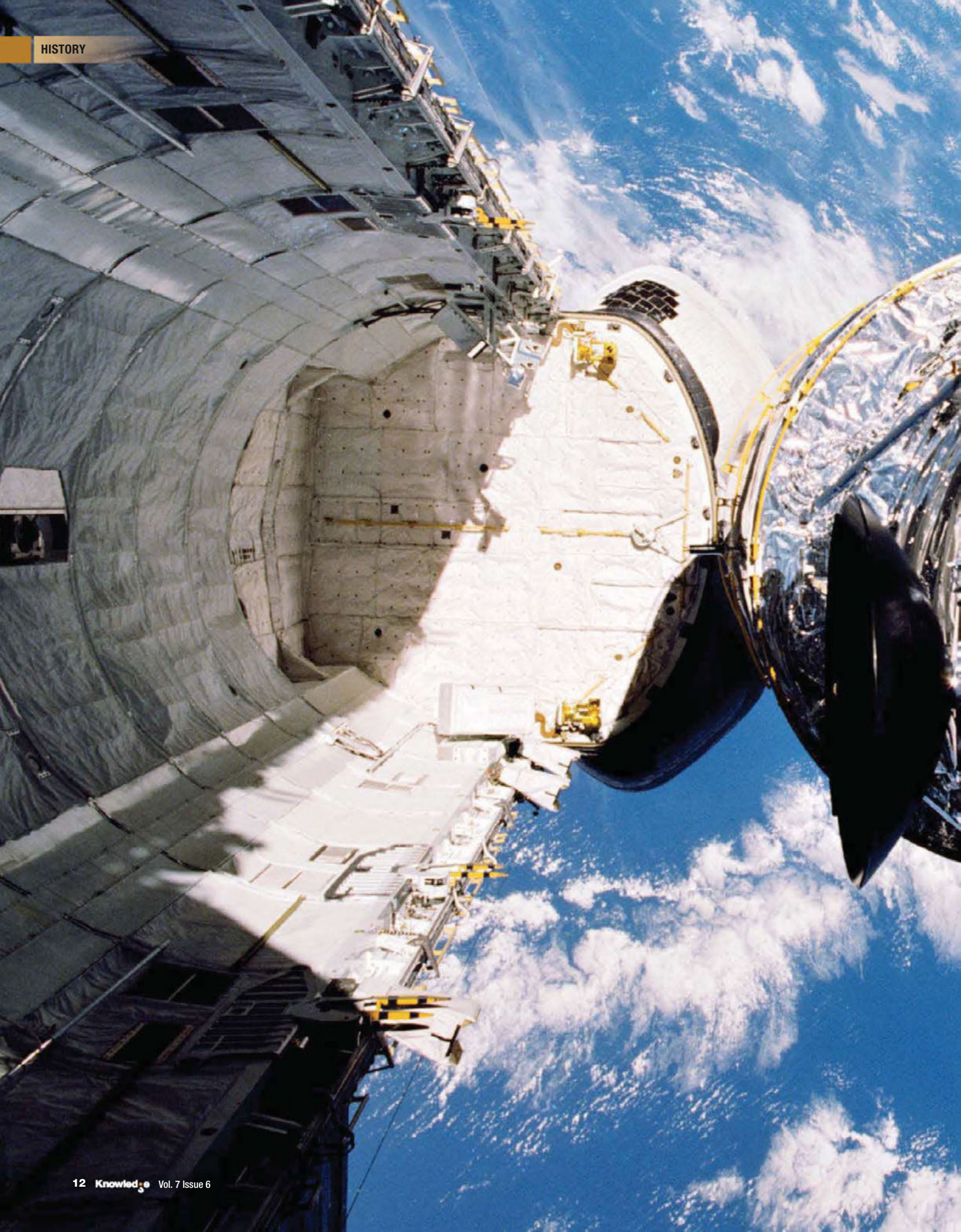
"Each type of polyp is so specialised; they can't survive independently," explains marine biologist and BBC radio presenter Helen Scales. "Hanging down are tentacles made from polyps with stinging cells that capture prey, dactylozooids; feeding polyps that secrete digestive juices, gastrozooids; and finally gonozooids that are in charge of reproduction."

The name comes from its supposed resemblance to an 18th-Century warship. They can be found in the Pacific, Indian and Atlantic Oceans.

"The sting is extremely painful," says Scales. "They can cause skin lacerations, convulsions and problems with breathing. Occasionally they're lethal. Their long tentacles can break off and retain their sting for days."

PHOTO: AARON ANSAROV







Deployment of the Hubble Space Telescope

In this April 25, 1990, photograph taken by the crew of the STS-31 space shuttle mission, the Hubble Space Telescope is suspended above shuttle Discovery's cargo bay some 332 nautical miles above Earth. The Canadian-built Remote Manipulator System (RMS) arm, controlled from in-cabin by the astronaut crewmembers, held the huge telescope in this position during pre-deployment procedures, which included extension of solar array panels and antennae. STS-31 was the tenth launch of the shuttle Discovery. On board were Commander Loren J. Shriver, Pilot Charles F. Bolden, Jr. (now NASA Administrator), Mission Specialists Steven A. Hawley, Bruce McCandless II and Kathryn D. Sullivan (now NOAA Administrator). To launch Hubble into an orbit that guaranteed longevity, Discovery soared to a record altitude of 600 km.

PHOTO: NASA



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WERE DRAGONS EVER REAL?

A new species of dinosaur uncovered in China resembles the mythical beasts



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EARTHS EVERYWHERE

Billions of planets in our own Galaxy could potentially support life



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FEELIN' GREEN

Sea slug's feat could help us cure genetic disorders

FIRST STEP TO ETERNAL YOUTH

Reversing the ageing process in human cells could one day treat genetic diseases

Telomeres are protective caps located on the ends of each strand of DNA. Now, Stanford University scientists have devised a means of increasing their length, which could have major implications for treating age-related diseases. Telomeres prevent chromosomes from deterioration. In young humans they're typically made up of 8,000 to 10,000 nucleotides, the subunits of DNA. Telomeres shorten each time a cell divides, and when they reach a critical length the



Telomeres are present at the end of DNA strands. Here, they can be seen as highlights on the end of the chromosome

GOOD MONTH/ BAD MONTH

It's been good for: Oldies

It seems that you can teach an old dog new tricks – they just learn in a different way. A study at University College London has found that rather than becoming gradually better at integrating different kinds of information, like 19- to 35-year-old whippersnappers, the over-60s learn new skills by suppressing what's less important.

Art lovers



Appreciating art and music may help boost immunity. A UC Berkeley team has found that the positive emotions engendered by experiencing art may decrease levels of pro-inflammatory cytokines. These proteins are associated with bad health.

It's been bad for: Credit card shoppers



Just four transactions was all it took to identify 90 per cent of the users in a credit card database of 1.1 million people, using time and place information. That was the finding of scientists in Denmark, who say that more advanced technologies are needed to protect data privacy.

Facebook users

Browsing on Facebook can lead to symptoms of depression if the site triggers feelings of envy among its users. Researchers from Missouri University carried out the study by questioning 700 Facebook users. The effect comes from users unfavourably comparing their own lives to those of others. Expensive holidays, new houses and happy relationships are the main contributors.



Dr Helen Blau's research could help treat or prevent age-related diseases

cell stops dividing or dies. This process is thought to play a key role in ageing.

In the study, the researchers treated human cells with modified messenger RNA. These are molecules that carry instructions from genes in the DNA to the cell's protein-making factories. The treated cells behaved like much younger cells, multiplying readily rather than stagnating or dying. Skin cells with telomeres lengthened by the procedure were able to divide 40 more times than untreated cells.

"We have found a way to lengthen human telomeres by as much as 1,000 nucleotides, turning back the internal clock in these cells by the equivalent of many years of human life," explains researcher Dr Helen Blau. "This new approach paves the way toward

preventing or treating diseases of ageing. There are also highly debilitating genetic diseases associated with telomere shortening that could benefit from a potential treatment."

The lengthening effect dissipates after around 48 hours, leaving the telomeres to continue to shorten with each cell division. This means that the treated cells don't go on to divide indefinitely – this would make the technique too dangerous to use in humans as there would be a risk of cancers developing.

"Existing transient methods of extending telomeres act slowly, whereas our method acts over just a few days to reverse telomere shortening that occurs over more than a decade of normal ageing," says researcher Dr John Ramunas. "This suggests that a treatment using our method could be brief and infrequent."

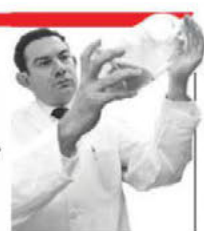
Timeline A history of ageing research

1825

British mathematician Benjamin Gompertz finds that mortality increases exponentially with ageing. This model is called the Gompertz Law of Mortality.

1961

American anatomist Leonard Hayflick (right) proposes the Hayflick limit. This is the maximum number of times that a cell is able to divide before cell division stops.



1977

Australian-American researcher Elizabeth Blackburn uncovers the molecular nature of telomeres while working as a postdoctoral fellow at Yale University.

1998

Andrea Bodnar discovers that the lifespan of cultured human cells can be extended with the addition of the enzyme telomerase.

1 MINUTE EXPERT

Methylation



What is it?

It's a biochemical process in which methyl groups, 'packets' of atoms consisting of one carbon atom bonded to three hydrogen atoms, tag onto DNA. It can switch genes on and off and plays an important role in many different biological processes.



Right. So what's new?

Four independent studies tracked the lives of nearly 5,000 people for up to 14 years. Those with larger numbers of methyl tags on their DNA were found to have shorter life spans than the others. The methylation is an indicator of a person's 'biological age'.



Biological age?

Yes. Biological age is a measure of how aged a person's body is. It seems to be a more accurate marker of how long a person has left than going by the number of years they have lived.



Got it. So what does this mean?

The researchers say that those with a faster-running biological clock died younger. Smoking, education, cardiac diseases and diabetes did not influence how fast that clock runs. A previous study found that cancer did have an effect. It is hoped that these findings will result in a deeper understanding of ageing.



PALAEONTOLOGY

Here be dragons

There can be few mythical beasts as synonymous with their country of origin as the dragon is with China. Now, palaeontologists have discovered a new species of dinosaur that resembles the legendary creature.

Qijianglong, meaning 'the dragon of Qijiang', was found at a fossil site first discovered by construction workers in 2006. It's about 15 metres long and lived 160 million years ago in the Late Jurassic. It belongs to a group of dinosaurs called the mamenchisaurids. These are unique to Asia and are known for their enormous necks, which can measure up to half their total length.

"*Qijianglong* is a cool animal. If you imagine a big animal that is half neck, you can see that evolution can do quite extraordinary things," says

the University of Alberta's Tetsuto Miyashita. "It is rare to find a head and neck of a long-necked dinosaur together because the head is so small and is easily detached after the animal dies."

Upon inspection, *Qijianglong* was found to have neck vertebrae that were filled with air, which is a unique trait among mamenchisaurids. This made the neck light, despite its huge size. Interlocking joints between the vertebrae suggest that the neck was more flexible when bending vertically than sideways.

The skeleton has been housed in a museum in Qijiang. "China is home to the ancient myths of dragons," says Miyashita. "I wonder if the ancient Chinese stumbled upon a skeleton of a long-necked dinosaur like *Qijianglong* and pictured that mythical creature."

WHO'S IN THE NEWS?

Barack Obama

President of the USA



What has he done this time?

At this year's State of the Union address, Barack Obama launched the Precision Medicine Initiative. This is a US\$215m research scheme with the goal of developing medical treatments that are tailored specifically to the genetics of patients, rather than taking a 'one size fits all' approach. It is part of

a broader effort to fund research and science.

What is 'precision medicine'?

According to the National Institutes of Health (NIH): "Precision medicine is an emerging approach for disease treatment and prevention that takes into account individual variability in genes, environment and lifestyle for each person."

That sounds pretty interesting. Tell me more...

The money is being divvied out among several organisations. At the centre of the project is a programme to give researchers across the world access to the health information of one million volunteers. This will help them to develop new medicines and treatment techniques.

DAVID SHUKMAN

The science that matters



Too little, too late?

Lonesome George, the last tortoise of his kind, at the Galapagos National Park

Back in 2009, 200 years after the birth of Charles Darwin, I was on an assignment in the remote Galapagos Islands. This is the biodiversity hotspot that the great scientist made so famous. Our focus was on evolution and, to our relief, it was remarkably easy to film the animals. The blue-footed boobies and marine iguanas seemed to pose for the camera rather than flee from it.

But one afternoon came an unsettling experience. My cameraman and I were allowed into the holy of holies: the well-guarded enclosure that was home to the most famous giant

tortoise in the world, Lonesome George. He was the last of his kind, a subspecies on the brink of extinction.

Darwin had written about extinction as a part of the rise and fall of competing forms of life, the flipside of evolution. Now, the towering dome of Lonesome George's shell shifted in the speckled light under a tree and his ancient head turned towards us. I know I was projecting my own emotions but, at the time, it felt that his eyes conveyed a desperate sadness. He died a few years later.

Some brilliant conservation schemes have restored the giant panda and the black-footed ferret. But their numbers never quite fell into single digits; assisted reproduction had a chance of working without causing inbreeding. Once the last band of survivors becomes too small, there is little hope.

That is the case with one of Africa's greatest mammals, the northern white rhino. Hunted for their horns, there are now just five left on the planet. One idea is to try IVF with eggs and sperm harvested before the animals die out. Another plan is

to gather stem cells and to freeze them in the hope that some day in the future it will be possible to create embryos.

And this raises a dilemma. Some argue that because we caused the demise of the species, we have a duty to use modern science to restore it. Others say that the medical interventions – probes and sampling and sedations – are harmful in themselves. And, all the time, yet more species face oblivion.

DAVID SHUKMAN is the BBC's Science Editor. @davidshukmanbbc

THEY DID WHAT?!

Chemists unboil an egg

What did they do?

A team from the University of California, Irvine figured out a way of untangling the proteins in cooked egg whites and allowing them to refold.

The resulting effect was as if the egg had been 'unboiled'.

How did they do it?

First, they cooked the eggs for 20 minutes so they were hard boiled. They then liquefied the cooked egg white with urea. This is a nitrogen-rich substance that is found in the urine of mammals. They then used a 'vortex fluid device'



that applied forces to the tiny strands of protein in the white. This separated the proteins back to their clear form.

What's the point?

Being able to reform proteins from yeast or *E. coli* bacteria may lead to more efficient methods of making proteins, which could help create cheaper cancer treatments.

10 DISCOVERIES THAT WILL SHAPE THE FUTURE

10

Temporary tattoo to measure blood glucose

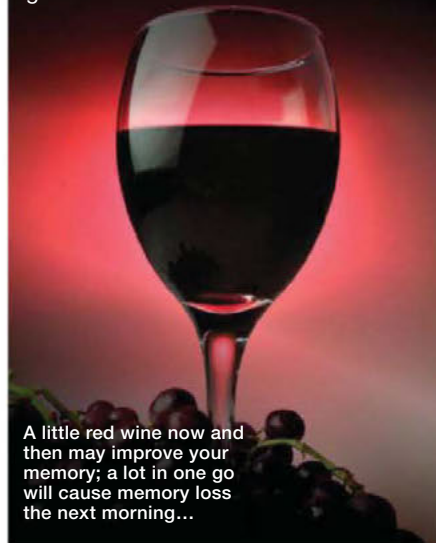
It seems tattoos may no longer be the preserve of footballers, rappers and Shoreditch hipsters. A group at the University of California has created a temporary paper-based tattoo that measures blood glucose levels using a mild electric shock. **The technology could replace the current finger-prick method.**

Take a blood test without the need for a needle



9 Compound in wine may aid memory

Resveratrol, an antioxidant found in the skin of red grapes, as well as in red wine, may help to **prevent age-related memory decline**. Researchers at Texas A&M University found that rats treated with the compound showed improved spatial learning and memory, and double the rate of growth of new neurones.

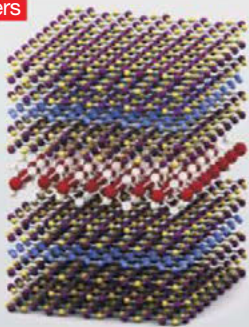


A little red wine now and then may improve your memory; a lot in one go will cause memory loss the next morning...

8 Graphene LEDs

Graphene could enable engineers to create the first generation of semi-transparent devices, according to research at the University of Manchester. The team constructed LEDs by combining different 2D crystals of graphene. **The tech could be used in everything from simple lighting to lasers and flexible displays.**

The components are just 10-40 atoms thick and emit light across their whole surface.



7 Stem cell treatment to reverse baldness



American researchers have turned stem cells into the cells that control hair growth

Going a bit thin on top? Fear not, **a team in the US has successfully used human pluripotent stem cells to generate new hair.** They coaxed the stem cells to become dermal papillae, which are cells that regulate hair follicle formation and growth. The treatment has been successful in rats, and the researchers now hope to try it in humans too.

6 Drug preserves brain function after stroke

Retigabine, a drug currently used for treating epilepsy, could **significantly reduce the debilitating effects of strokes**. A team in Texas found that the drug greatly reduced damage to brain tissue when tested in mice that had suffered strokes. It also helped to preserve motor functions such as balance and coordination.



5 Liquid sunshine

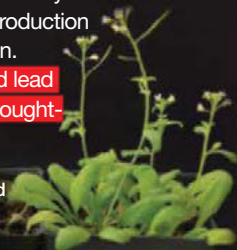
The fuel in your car may one day be produced by genetically modified bacteria. Harvard scientists have designed a system that uses an 'electric leaf' to liberate hydrogen from water using sunlight. The bacterium *Ralstonia eutropha* then absorbs the hydrogen and **combines it with carbon dioxide to create the liquid fuel**, isopropanol.

3 Drought-tolerant plants

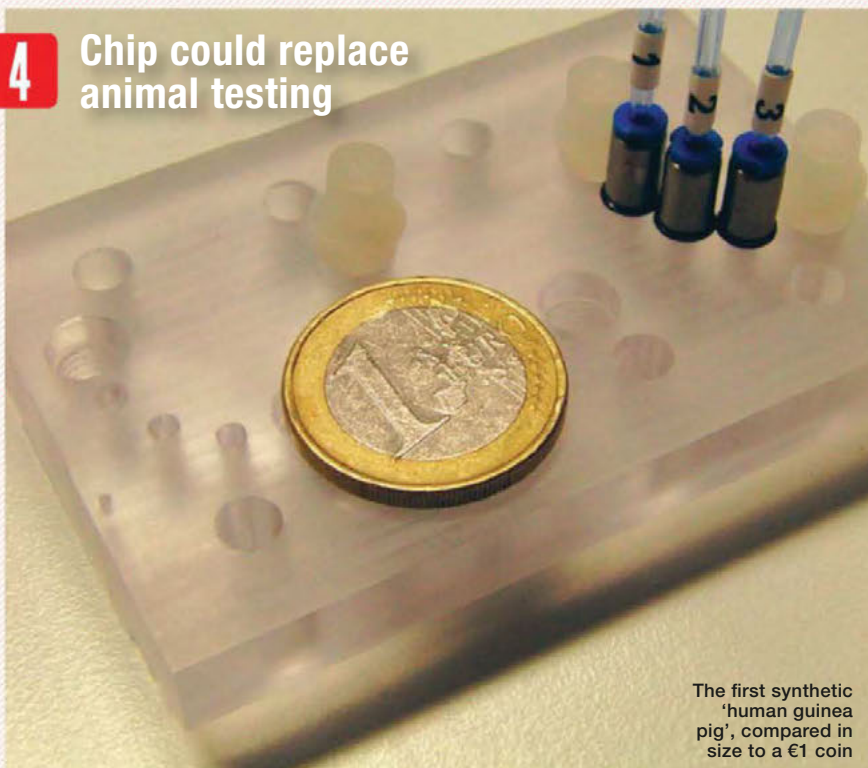
Humans are not the only ones struggling with the effects of climate change – plants are too. Help may be on the way, as researchers in California have used synthetic biology techniques to help plants conserve water by encouraging the production of a specific protein.

The research could lead to harder, more drought-resistant plants.

Hardier plants could soon be arriving in our gardens



4 Chip could replace animal testing



The first synthetic 'human guinea pig', compared in size to a €1 coin

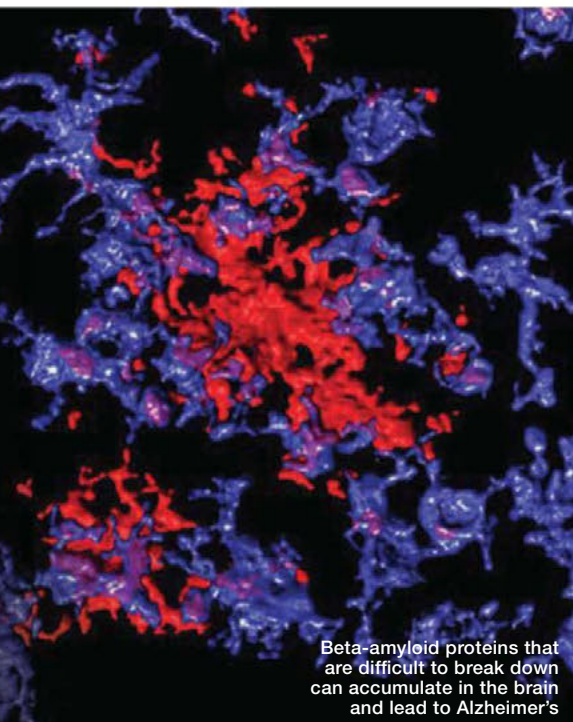
A team in Berlin has produced a multi-organ chip that could **reduce the need for animal testing**. Cells from various organs can be placed in the chip and

used to simulate processes that occur within the human body. The substance to be tested is then introduced into the chip and its effects are monitored.

2 Immune cells may help fight Alzheimer's

Alzheimer's disease is an irreversible, progressive brain disease that causes problems with memory, thinking and behaviour. Brains with Alzheimer's disease show build-up of a sticky plaque. This is made of a protein called beta-amyloid and induces memory loss. A team in California has found that inhibiting a substance called interleukin-10 in mice activates an immune response to clear the brain of plaques, restoring brain cells that were damaged.

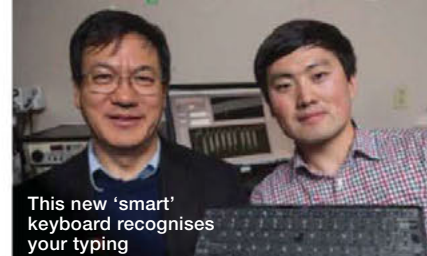
The work could lead to more effective human therapies.



Beta-amyloid proteins that are difficult to break down can accumulate in the brain and lead to Alzheimer's

1 Intelligent keyboard

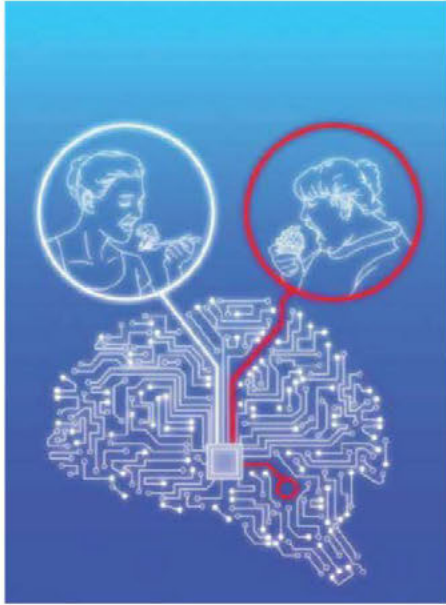
Always forgetting your passwords? There may soon be a solution. Engineers at the Georgia Institute of Technology have created a keyboard that can identify users by their typing style. The keyboard is capable of recording key strokes to create a profile for users. **It could be used instead of, or as well as, regular passwords for security.**



This new 'smart' keyboard recognises your typing

HEALTH

Overeating solved?



If your sweet tooth is causing you to pile on the pounds, you may want to read on. Researchers at MIT have identified a neural circuit that controls compulsive sugar consumption.

Compulsive overeating is a reward-seeking behaviour that's similar to drug addiction. But because eating is needed for survival, any successful therapies need to separate the neural mechanisms that cause overeating from those responsible for normal eating.

The team found success when manipulating a neural pathway connecting the lateral hypothalamus, an area of the brain involved in hunger, to the ventral tegmental area, which is involved with the brain's natural reward circuitry.

Activating this pathway caused well-fed mice to spend more time eating. It also increased their consumption of a sugar solution placed separately from their food, even when they had to cross an electrified platform to reach it. Inhibiting this pathway in hungry mice reduced the sugar-seeking behaviour without decreasing normal food consumption.

"Although obesity and Type 2 diabetes are major problems in our society, many treatments do not tackle the primary cause: unhealthy eating habits," says author Dr Kay Tye. "Our findings are exciting because they raise the possibility that we could develop a treatment that selectively curbs compulsive overeating without altering healthy eating behaviour."

PHOTO: UNIVERSITY OF ALBERTA, PRESS ASSOCIATION, PETE SOUZA/WHITE HOUSE ILLUSTRATOR: DEM ILLUSTRATION

SPACE

Why there's an Earth-like planet around every star

Planetary scientists have calculated that there are billions of Earth-like planets in our galaxy that could potentially support life.

A team at the Australian National University made the calculation using the Titius-Bode law, along with knowledge of the thousands of exoplanets that have been discovered by the Kepler Space Telescope.

The Titius-Bode law was created 200 years ago and can be used to predict the positions of planets orbiting a star. Due to the method used to spot them, the Kepler Space Telescope is more likely to find planets that are very

close to their stars. Using the Kepler data as a starting point, they then applied the Titius-Bode law to predict the existence of planets further away from their stars.

They found that the standard star has roughly two planets in the so-called Goldilocks zone. This is the distance from the star where liquid water, crucial for life, can exist. If the calculation is correct, it would mean there are 200 billion Earth-like planets in the Milky Way alone.

But don't get too excited just yet. The university research team says it is highly unlikely that these exoplanets are home to



Kepler-62f is an Earth-like planet that orbits in the habitable region of its star

thriving alien civilisations.

“The ingredients for life are plentiful, and we now know that habitable environments are plentiful,” says researcher Dr Charley Lineweaver. “However, the Universe is not teeming with aliens with human-like intelligence that can build radio telescopes and spaceships. Otherwise we would have seen or heard from them. It could be that there is some other bottleneck for the emergence of life that we haven’t worked out yet. Or intelligent civilisations evolve, but then self-destruct.”

CLICK HERE

New websites, blogs and podcasts



Andromeda Bot

twitter.com/AndromedaBot

Hubble released the largest ever photo of the Andromeda galaxy in January 2015. This Twitter account tweets a new section of the picture every hour, allowing you to see individual stars in all their

glory. According to the European Space Agency, you’d need over 600 HD TV screens to display the image in full.



Edible Education

food.berkeley.edu/edible-education-101/

Ever felt like you should know more about where your food comes from, and how it could be more sustainable? This lecture course at the University of California, Berkeley, is

exploring those questions and more. The first lecture was on 26 January, but course materials are freely available online.



Jurassic World

jurassicworld.com/dinosaurs/

Jurassic World is almost here, and if you want to brush up on your dinosaur knowledge, then look no further than the film’s website. The jury is still out on exactly how scientifically accurate the film will be (the

dinos in the trailer lacked feathers) but, either way, everyone’s going to be talking about them come summer.



Brainwave

<http://bit.ly/1ESDRcT>

The Open University’s Brainwave app consists of five games that test your cognitive ability. But this isn’t your average brain-training game. It can tell you if you’re a morning or evening person

based on your scores at different times of day. Your results will then be made anonymous and uploaded to help with real psychological research.



PATENTLY OBVIOUS

Inventions and discoveries that will change the world with James Lloyd



Silent movies

The music swells and a roomful of cinemagoers grip their seats as the hero moves in for a kiss. His dewy-eyed lover gazes back, and then... rrrrrrrrrrr! It's your phone, and now the whole cinema is looking your way.

A new patent from Microsoft promises to make inopportune phone calls a thing of the past. The technology will put your phone into 'inconspicuous mode' when you're in the cinema, disabling the sound and dimming the screen so you don't disturb your fellow popcorn-munchers.

Microsoft's system will automatically detect when you're at the movies, by monitoring your GPS location, checking your calendar for cinema trips, noting details of tickets bought online, or even sensing changes in light levels. It could also be used in meetings, the bedroom or on public transport, meaning you'll never be ejected from the Quiet Coach again.

Patent number: US 8,934,879

Doze on demand

When chamomile tea doesn't do the trick, here's a new way to help you drop off: Sprayable Sleep. The concoction has been developed by a team in the US and contains just three ingredients: water, tyrosine (an amino acid) and melatonin, the hormone that regulates our circadian rhythms and is often used to treat sleeping disorders. Once in contact with the skin, Sprayable Sleep is absorbed by the body, providing a release of melatonin that the makers say gives a natural-feeling sleep without the grogginess often associated with sleeping pills.

Patent pending

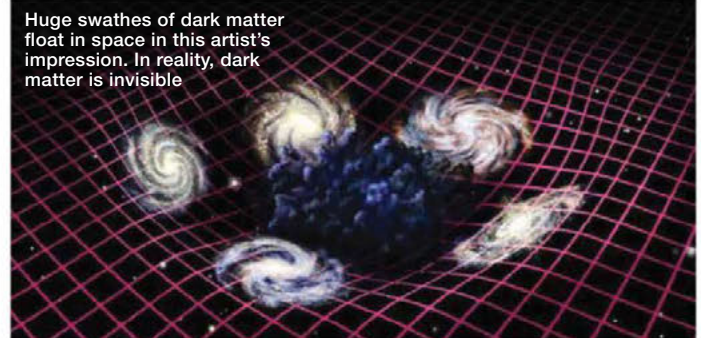
Pocket power

Are your gadgets always running out of juice? A portable power generator could be the solution. Kraftwerk is a lightweight device that uses fuel cell tech to convert camping gas into electrical power. Developed by materials scientist Dr Sascha Kühn, the device is capable of charging 11 iPhones with just one load of gas. Using gas instead of batteries means that kraftwerk can be quickly refilled. As you don't need to be anywhere near a power socket, it's a perfect solution for those camping trips.

Patent pending

PHYSICS

'Crazy' particle explains the Universe's missing mass



Huge swathes of dark matter float in space in this artist's impression. In reality, dark matter is invisible

It's one of the biggest questions in science: what is dark matter, the missing stuff that makes up 85 per cent of the Universe's mass?

A team from the University of Southampton is proposing that it could be made up of a new type of particle. The particle's mass is about 0.02 per cent of an electron's and does not interact with light. But it does interact strongly with normal matter.

"Our candidate particle sounds crazy, but currently there seem to be no experiments or observations which could rule it out," says co-author Dr James Bateman. "Dark matter is one of the most important unsolved problems in modern physics, and we hope that our suggestion will inspire others to develop detailed particle theory and even experimental tests."

Though it cannot be seen with telescopes, dark matter is thought to exist due to otherwise unexplained gravitational effects on stars and galaxies. The team says their proposed particle would be unable to penetrate the Earth's atmosphere, making detection from the ground impossible. They are hoping to incorporate searches for it in the upcoming space experiments being carried out by the MAQRO consortium.

"At the moment, experiments on dark matter do not point in a clear direction. Given that the Large Hadron Collider at CERN has not yet found any signs of new physics, it may be time that we shift our paradigm towards alternative candidates for dark matter," explains co-author Dr Alexander Merle.

NATURE

Solar-powered slug



The emerald green sea slug takes genes from the algae it eats and uses them to generate energy through photosynthesis, Chicago University scientists discovered.

It is one of the only known cases of functional gene transfer from one multicellular species to another.

"There is no way that genes from an alga should work inside an animal cell," says co-author

Prof Sidney K Pierce. "And yet here, they do. They allow the animal to rely on sunshine for its nutrition. If something happens to their food source, they have a way of not starving to death until they find more algae to eat."

Researchers hope to mimic this process to correct genetic diseases in humans.

Comment & Analysis

Starter snowboarders learn to love friction...

After slithering inelegantly to a stop, I sat down slightly too hard on the snow and surveyed the scene. The board attached to my feet was decked out in a colour scheme oozing daredevil chic (implying, unreasonably, that I also belonged in that category). A bit further down the slope was my snowboarding instructor, almost entirely hidden behind beard and goggles, and clearly accustomed to waiting patiently. Beyond him was a lot of white, flowing down the mountain towards distant hot chocolate, warmth and safety. “You’ll like this,” the beard said, “I’ll draw you a diagram.”

He traced out a curve for the path of the snowboard, and another curve for the path of my centre of mass. I suddenly felt a wave of comeuppance arrive. I’ve been drawing diagrams like that for years: idealised situations where point-like objects respond to uncomplicated forces are the bread-and-butter of physics. But these diagrams almost always leave something important out. And the problem with my current situation was that this time, the important thing wasn’t ever really there. There was almost no friction. My first snowboarding lesson was actually a lesson in navigating the idealised world I’d been drawing for years. And it was painful.

Friction gets a bad rap, but what it really gives us is control. It heads off the conservation laws – conservation of momentum and conservation of energy – by providing an escape valve. Walking is only possible because of friction with the floor. Wheels wouldn’t work if they couldn’t grip. Energy leaches away via friction, so we have to consciously supply more energy to keep going.

There are alternative ways to control our movement, but snowboarding really highlights their limitations. You can change the position of your centre of mass to rotate about a pivot point. You can plough up snow in front of your board to give you something to push against. But there’s no room for misjudgment – get it wrong and your coccyx is going to suffer. This is Newton’s laws of motion writ large: a body will continue either at rest or in motion unless a force is applied to it. Forces accelerate you, and for every action there’s an equal and opposite reaction. That last one made me terrified of the trees.



“Friction, far from being the curse of our world, is one of the most useful tools we have. And I have the bruises to prove it”

Of course, you do need a bit of friction for snowboarding to work. But the thrill of the sport comes from the freedom of mostly doing without friction, while maintaining control of the tiny bit that’s left so that you don’t kill yourself. As I looked down the hill, a baggy blur of colour swooshed past, clearly as close to an idealised frictionless diagram as a human could get. “Turning is useful because it slows you down,” my instructor said, before zooming off to demonstrate his point. As I

stood up to re-start my semi-controlled falling, it became obvious that energy loss – that universal nuisance of the physical world – had suddenly become the most precious tool I had. I wondered whether Newton had been ice-skating before he wrote down his laws of motion. He did live in an era when there were frost fairs on the River Thames, but I’ve never heard anyone mention a link.

I loved that day on the mountain, and maybe I’ve caught the snowboarding bug. But exciting as the idealised world of frictionless physics was, I wouldn’t like to live there. Friction, far from being the curse of our world, is one of the most useful tools we have. And now I have the bruises to prove it!

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose most recent series is *Super Senses*

ILLUSTRATOR: ANDREW LYONS



Discover the UNIVERSE NEXT DOOR ...where time runs backwards



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A brand new idea about the Big Bang reveals why our clocks always go forwards, explains **Marcus Chown**

The Big Bang may not have spawned one universe, it may have spawned two. One is our Universe, where time runs normally. The second is a twin universe in which time runs backwards. The latter universe, located 'on the other side of the Big Bang', would appear completely normal to its inhabitants, with stars and galaxies congealing from the cooling debris of the Big Bang much like in our Universe. If it were



→ possible for us to look back through the Big Bang to this cosmic doppelgänger, its backward-running time might make it appear like a universe in reverse, contracting to a Big Crunch.

Dr Julian Barbour of the University of Oxford, Dr Tim Koslowski of the University of New Brunswick and Dr Flavio Mercati of the Perimeter Institute in Ontario made this extraordinary discovery while trying to understand one of the great puzzles of physics: why there is a direction of time. We commonly associate this 'arrow' of time with the way in which eggs break, people grow old and castles crumble. We never see eggs unbreak, people grow young and castles un-crumble. But why we do not isn't as obvious as it might seem.

Arrow of time

The problem is that all the fundamental laws of physics are 'time symmetric' – they permit processes to work equally well backwards as forwards. For instance, an atom can spit out a photon of light and it can also suck in a photon of light. If you were shown a film of an atom doing something, you would never be able to tell whether the movie was being run forwards or backwards. Both events would appear perfectly reasonable. In contrast, if you were shown a picture of a complete teacup and the same cup smashed into tiny shards, you would be in no doubt that the picture of the broken cup was taken later.

This so-called thermodynamic arrow of time is associated with the change from order to disorder. And, obviously, this can happen only if the Universe was in a more ordered state in the past. The trouble is that an ordered state is a special state – it smacks of something set up by God, which makes it uncomfortable for physicists to accept.

The 19th Century German physicist Ludwig Boltzmann speculated that, although the Universe on the whole was disordered, by some incredible fluke we happen to live in a super-ordered location. It could be considered a rare 'statistical fluctuation' – the cosmic equivalent of an unbreaking cup. Most physicists consider this an unsatisfactory conclusion since it merely explains the specialness of our Universe in terms of some other specialness.

Long after Boltzmann's time, it was discovered that the Universe burst into being 13.82 billion years ago in a titanic explosion called the Big Bang, and that all the galaxies, including our Milky Way, congealed out of the cooling debris. This put the question of the origin of the arrow of time into sharper focus. Now it



“We never see eggs unbreak, people grow young and castles un-crumble. But why we do not isn't as obvious as it might seem”



Above: You never see castles un-crumble, which puzzles physicists

Right: The Universe's matter rapidly expanded after the Big Bang took place

appeared that the Big Bang must have been in a highly ordered and special state. Again, this is something that physicists find equally difficult to stomach.

Another logical possibility is that the Universe goes from order to disorder. This is not because it was super-ordered in the past, but because there is an infinite scope for increasing disorder in the future. This possibility has been pointed out by physicists Sean Carroll and Jennifer Chen of the California Institute of Technology in →



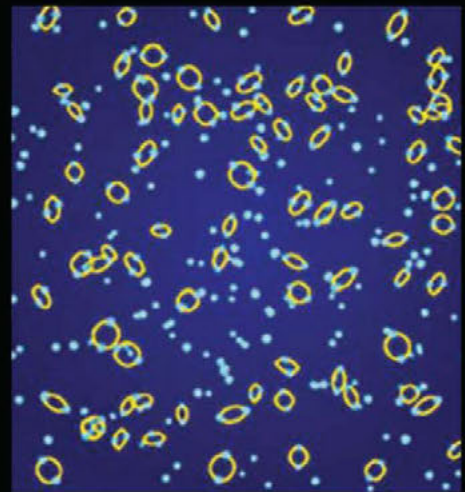
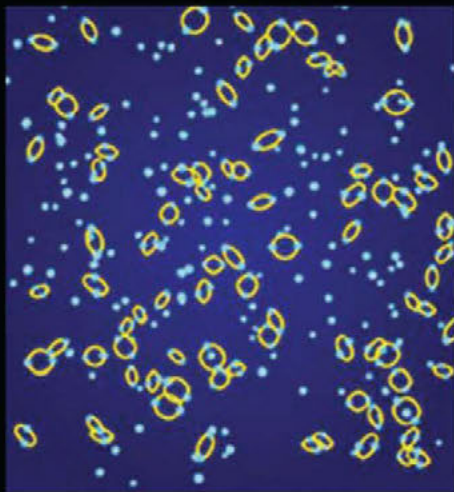


PHOTO: SCIENCE PHOTO LIBRARY X2, ADAM WALANUS/CC, APS/ALAN STONEBRAKER



Pasadena. One popular theory of the origin of the Universe is called eternal inflation. Here, the Universe keeps spawning baby universes, which in turn spawn their own baby universes, and so on. Carroll and Chen contend that this ensures the Universe becomes ever more complex and disordered, so there will always be scope for increasing disorder.

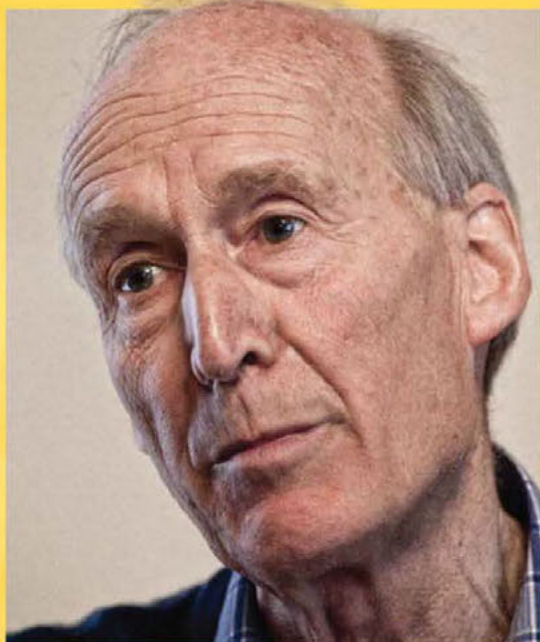
What the super-ordered past and the super-disordered future have in common is they are, respectively, 'initial' and 'final' conditions imposed on the laws of physics. But what if the laws of physics themselves actually impose an arrow of time? In research published in October 2014, Barbour and his colleagues made an unexpected discovery

Top: The Big Bang may have spawned two different universes

Above: A simulation of 1,000 particles floating in space. The central image shows the start point. The other images show the two possible future scenarios

suggesting that this could indeed be the case.

Barbour's team simulated 1,000 massive particles floating in space. In previous work, other physicists have discovered that such a group of particles, influenced only by the mutual attractive force of gravity, will tend to cluster in small groups after a long period of time. These are generally seen as pairs of masses, orbiting each other. Barbour and his colleagues used this as their starting point and were able to simulate what would happen to their 1,000 particles, but crucially without any reference to time. They were aided by a special formulation of physics known as 'shape dynamics'. Here, it is only the shape of a configuration of particles that is important rather



“The key feature of the model is that every single solution has two oppositely pointing arrows of time”

Dr Julian Barbour from the University of Oxford on the arrow of time



than their absolute separation. In shape dynamics, the ratio of the greatest distance between particles to the smallest can be taken as a measure of complexity.

Barbour’s team found that, in pretty much every starting configuration, the cluster went through a state of maximum compactness and minimum complexity, which they associated with the Big Bang. Crucially, from this state, the collection of particles could evolve in two possible ways. “The key feature of the model

Dr Julian Barbour (left) carried out the simulations of 1,000 particles, which suggested another universe



TIME TRAVELLERS

If the Universe ever contracts to a point, it could explain the mystery of dark matter

If the reason things get more disordered is that the Big Bang was in an ordered state, then this leads to a conclusion: cups break and coffee grows cold because distant galaxies are flying away from us in the aftermath of the Big Bang. It is the ultimate connection between the everyday and the cosmic.

So what would happen if cosmic expansion were to one day run out of steam, and the Universe started contracting down to a Big Crunch? The answer is that the Universe, rather than getting more disordered, would get more ordered. In such a circumstance, as pointed out by Thomas Gold of Cornell University in 1958, time would run backwards.

This has prompted an outrageous suggestion for the identity of the Universe’s dark matter. Dark matter outweighs the visible stars and galaxies by a factor of about six and reveals itself through its gravitational tug on the visible stuff. In 2000, Lawrence Schulman of Clarkson University in New York showed in a computer simulation that stuff with a normal arrow of time could co-exist with stuff with backward arrow. Just as stuff with a normal arrow of time can survive into the contraction phase of the Universe, reverse-time stuff from the contraction phase can survive into our phase.

What would this stuff look like? If the Universe ever makes the transition from expansion to contraction it is likely to happen at least 100 billion years in the future. By this time, most of the stars will have burnt out. So any relics from the future surviving into our expanding Universe will give out no light. They will appear, according to Schulman, just like dark matter!



After the Big Bang, the Universe started expanding and is getting more disordered. If it contracts in a Big Crunch, time would run backwards

→ is that every single solution has two oppositely pointing arrows of time,” says Barbour. “This is an entirely new result,” he explains. “All other proposed solutions for the existence of an arrow of time of which I am aware require special initial, final or two-time conditions to be added to the law.”

The other side

This research suggests that we live in one Universe, but there is another ‘on the other side of the Big Bang’ where time goes backwards relative to us. In this picture, the Big Bang is not the beginning of the Universe, as everyone imagined, but merely the mid-

ORDER OR DISORDER?

Some key laws of physics can all be explained by a smashed mug

How do fundamental laws that make no distinction between processes happening in one direction of time compared to another result in an everyday world where things happen in only one direction? The answer was discovered by the 19th Century physicist Ludwig Boltzmann.

Imagine a mug. There is only one way it can be intact, but there are a huge number of ways it can be broken. For instance, it can be in one big fragment and 10 smaller fragments, or two big fragments and seven smaller fragments, or two big fragments and dozens of dust-sized fragments. And so on. Now, if all possibilities are equally likely, it is overwhelmingly probable that the mug will go from being intact to being broken. It is not impossible that the broken fragments will leap back together to make an intact mug, but it's so unlikely that you would probably have to wait many times the current age of the Universe to see it happen. What characterises all the changes we see around us - from mugs breaking to castles crumbling and people growing old - is a transition from order to disorder. It is this transition which sets the direction of the thermodynamic arrow of time. In physics, disorder goes by the technical name of ‘entropy’. And one of the most famous laws in physics - the Second Law of Thermodynamics - says that “entropy never decreases”. These words are even inscribed on Boltzmann's headstone in Vienna.

It is highly unlikely that these pieces will jump back together again... but it's not impossible



Above: The way particles interact with one another was used to show that there could be two universes



“This is an important step forward in our understanding of the time asymmetry of the Universe”

Dr Lee Smolin of Ontario's Perimeter Institute discusses Barbour's research



point in its life. The doppelgänger universe will appear to its inhabitants just as our expanding Universe appears to us, though with different galaxies and stars. The expectation might be that if we could see our twin universe, everything would be going backwards – like a film in reverse. But Barbour says it's impossible to say if this would be the case. “Our model is very simple and we would have to ‘add’ light so that observations can be made and questions like this answered.”

In Barbour's team's scenario, the law of gravity both imposes an arrow of time and doesn't. Although the inhabitants of each universe experience an arrow of time, the two arrows are opposite and cancel each other out overall. The source of the direction of time appears to be the law of gravity. This is very unexpected because the law of gravity is time

symmetric. “This feature has been sitting [unnoticed] inside Newtonian gravity ever since the first evidence for it was discovered by [Joseph-Louis] Lagrange in 1772!” states Barbour.

“This is important in our understanding of the time asymmetry of the Universe,” says Dr Lee Smolin of the Perimeter Institute. “I don't think it's the whole story. But it's a major insight.”

Barbour's model is a simple one that employs only Newtonian gravity. However, our Universe is orchestrated not by Newtonian gravity but by Einstein's more complicated General Theory of Relativity. Nevertheless, the physicists say that the features of Newtonian gravity which lead to their result are also present in Einstein's theory.

Barbour cautions that all his team has shown is that there's a gravitational arrow of time – that is, a direction of time naturally emerges in a system subject to Newtonian gravity. He believes, however, that it will be possible to show that the “thermodynamic arrow of time” – which governs everyday life and causes cups to break and people to grow old – is a natural consequence of the gravitational arrow of time. Watch this space.

MARCUS CHOWN is a science writer and broadcaster whose most recent book is *What A Wonderful World*

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NASA's Dawn mission
is scheduled to arrive
at Ceres in April. **Colin
Stuart** reveals how our
understanding of this
intriguing dwarf planet
has evolved over time



ELLY PLANET

Picture the scene: Italy, 1 January 1801. Most of the population are ringing in the new year, but Giuseppe Piazzi is scanning the skies with a telescope.

For the previous few decades, astronomers had noticed a sizeable gap in the Solar System between the orbits of Mars and Jupiter. Some had even predicted a missing planet in the region. That night, Piazzi found it. Our neighbourhood's new addition was christened Ceres, after the goddess of agriculture. The number of known planets nudged up by one – at least temporarily.

At 950km across, and sitting 2.8 times further away from the Sun than the Earth, today we know that Ceres is the largest body in the asteroid belt – the group of small, rocky objects tumbling around the Sun between the inner and outer planets. Ceres makes up around 25 per cent of the entire





The Delta II rocket launched the Dawn spacecraft in September 2007

mass of the belt. Even today, the debate still rumbles over what to call it. After Piazzini's discovery, it was labelled by some as a fully fledged planet. It remained that way in a number of scholarly texts for over 50 years. It then spent the 20th Century as simply the largest asteroid, and is still considered one today. In 2006 came yet another revision. The decision by the International Astronomical Union that saw Pluto demoted from a planet to a dwarf planet saw Ceres gain the same status. Ceres remains the only dwarf planet in the inner Solar System – the rest orbit further out than Pluto.

Class wars

It is easy to see why Ceres and its flip-flopping classification continues to attract attention from astronomers: its true nature needs nailing down once and for all. Until recently, our best images of Ceres came from the Hubble Space Telescope. Over 200 images were snapped in an observing run between December 2003 and January 2004. The photos revealed an

Above: In this artist's impression, Ceres is seen in the foreground, looking towards the Sun and the inner planets



VESTA

Dawn visited this asteroid before continuing its mission to Ceres

Vesta is both the second and third biggest asteroid, depending on how you classify size. At 525km in diameter, it is smaller than Ceres and Pallas. However, only Ceres is heavier.

Vesta was detected on 29 March 1807 by Heinrich Olbers, almost five years to the day after he discovered Pallas and six years after Piazzini spotted Ceres.

Vesta's surface sports two enormous craters named Rheasilvia and Veneneia. The former covers 95 per cent of

the southern pole and takes its name from the mother of Rome's founders, Romulus and Remus.

As well as craters, the surface of Rheasilvia features long troughs. The largest – Divalia Fossa – measures 465km, which is longer than the Grand Canyon.

Vesta is one of only five Solar System bodies that we have samples of here on Earth. These arrived via meteorites. The others are from Mars (meteorites) and missions to the Moon, the comet Wild 2 and the Itokawa asteroid.



CERES

The Dawn mission should help clear up this dwarf planet's identity crisis

Ceres is the smallest of five currently recognised dwarf planets. The others, from biggest to smallest, are Eris, Pluto, Makemake and Haumea.

A total of 24 astronomers (known as the 'celestial police') were searching between Mars and Jupiter for planets at the turn of the 19th Century. But it was Giuseppe Piazzi, not one of them, who found Ceres in 1801.

Dawn will orbit Ceres at a height of 5,900km. After five

months it will be lowered to 1,300km, then drop to 700km after a further five months.

Being small, Ceres's gravity is only 3 per cent of Earth's. Such low gravity makes it an ideal target for human space exploration as it is easy to take off again from its surface.

Ceres is located almost three times further away from the Sun than us, so it will take over 20 minutes for data from the dwarf planet to be relayed to Earth.

almost perfectly round, planetesque form – strikingly different from the asteroids with their jagged, irregular shapes. From its density and rotation rate it seemed plausible that, like a rocky planet, Ceres has layers. These constitute a rocky core, an icy mantle and an outer crust. The debate intensified.

The view from Hubble was intriguing, but could only take us so far. "Hubble's resolution is good, but it wasn't telling us everything we wanted to know," says Dr Carol Raymond, from NASA's Jet Propulsion Laboratory in California. Enter NASA's Dawn mission, for which Raymond is deputy principal investigator.

Dawn was launched in September 2007. By July 2011 it had reached Vesta, which is one of Ceres's large neighbours in the asteroid belt. It spent over a year in situ before departing in September 2012 with a course set for Ceres. It is the first craft designed to go into orbit around two Solar System bodies. Earlier this year, on 25 January, it edged close enough to Ceres for its cameras to exceed the clarity of Hubble's view for the first time. The mission plan was for it to enter

"Planetary scientists generally think the planets were made out of smaller pieces. Is Ceres one of those building blocks?"



Prof Christopher Russell is the principal investigator of the Dawn mission

into orbit around Ceres on 6 March 2015. Once there, it is set to spend almost a year trying to unlock its secrets.

Early origins

As Ceres is such a unique object in the asteroid belt, one of the main goals is to work out its origins. One theory is that there were once many more objects like it, but over time they came together under gravity to form the rocky inner planets. Ceres was left out in the cold.

"Planetary scientists generally think the planets were made out of smaller pieces. Is Ceres one of those building blocks?" asks Dawn's principal investigator Prof Christopher Russell.

A more extreme option is being considered by some astronomers: Ceres is an imposter. The suggestion is that its uniqueness in the asteroid belt is because it didn't actually form there. Instead, they say, it began life out beyond Neptune in the Kuiper Belt – the same region of the outer Solar System in which Pluto



DAWN SPACECRAFT

The craft is full of innovative tech to help it complete the mission to Ceres

The Dawn mission is part of NASA's Discovery Program, which seeks to unlock the mysteries of our Solar System. The programme launches lots of smaller space trips to work in harmony with NASA's larger and more expensive 'flagship' missions. Dawn combines cutting-edge technology from other missions with spare parts and apparatus from earlier space trips.

1

Star tracker

Dawn is able to orientate itself in space by using its two star trackers to keep watch on its position relative to fixed stars

2

Cameras

Two 5.5kg cameras will snap close-up images of Ceres throughout the mission. The images will then be sent to Earth

3

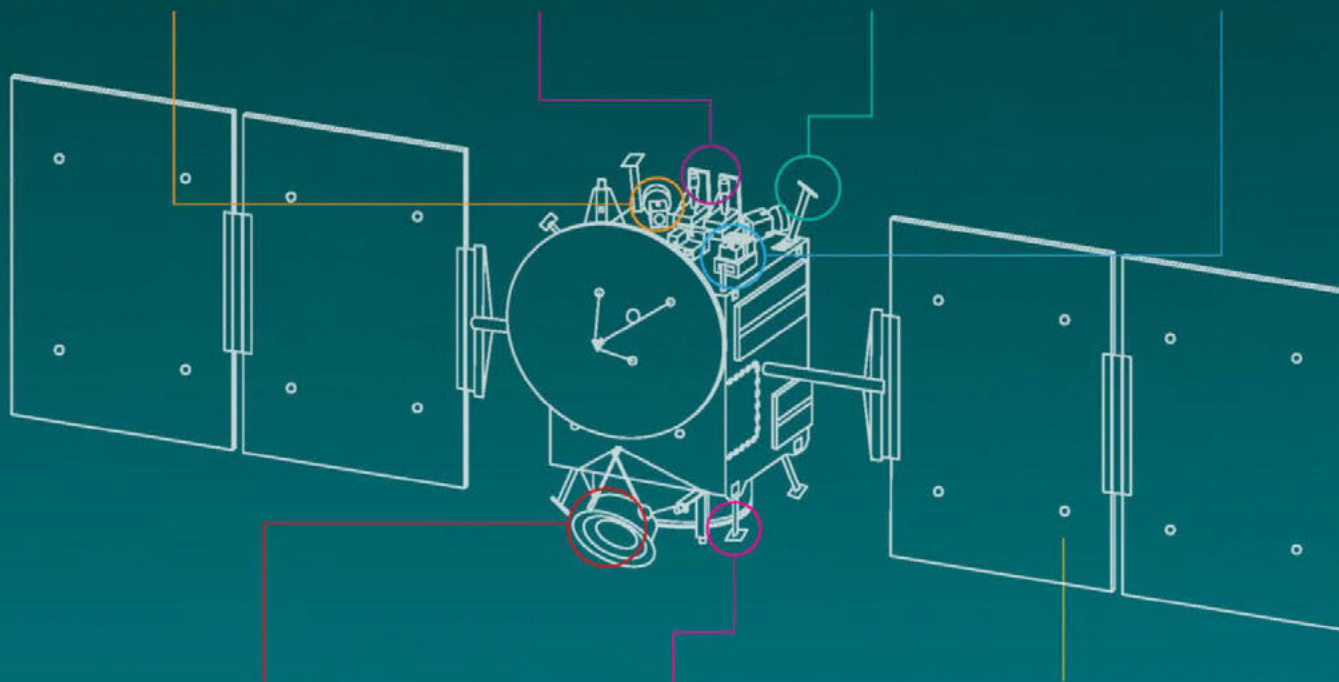
Spectrometer

By gathering sunlight reflected by Ceres, scientists can calculate various values such as its surface temperature

4

Gamma ray and neutron detector

This can help determine which elements comprise the surface of Ceres



5

Ion thruster (1 of 3)

Three high-tech ion thrust units allow for greater manoeuvrability. Dawn has been able to visit Vesta and Ceres in one mission

6

Antennas

The Dawn spacecraft has four antennas which can be used to communicate with Earth. The longest is 1.52m in length

7


Solar panels

The ion thrusters are powered by energy gathered through Dawn's solar panels. When extended they make the probe almost 20m wide

“The Herschel Space Telescope spied a cloud of water vapour around the dwarf planet”



From left: Earth, Ceres and the Moon

 resides – before drifting to its current location. That would mean Ceres and its dwarf planet cousins have more in common than just a name.

So which is it? Some clues have already been gleaned from Dawn’s initial stop at Vesta. “We chose Vesta because it was thought to be the parent body of the HED [howardite-eucrite-diogenite] meteorites which are very ubiquitous in our collection,” says Raymond. Chemical analysis using Dawn’s instruments confirmed that suspicion. In situ measurements of Vesta were conducted alongside detailed lab studies of the HED meteorites. The results pointed to a swift beginning. “It seems Vesta formed very quickly, perhaps within the first million years of the Solar System,” says Raymond.

The key is a radioactive isotope of aluminium, known as aluminium-26. This isotope is known to have been present in the early Solar System, but decays over time. As Vesta formed early, it was able to gather up a significant amount of aluminium-26. The decay happened inside the asteroid, and the heat produced helped govern its geology. By comparing the structures of Vesta and Ceres, it should be possible to estimate when the latter formed. The older it is, the more likely it formed in its current location and not in the outer Solar System.



Italian astronomer Giuseppe Piazzi discovered Ceres in 1801

Water problem

Another important indicator is the movement of water, or lack of it. From measurements of its density, it is thought that H_2O accounts for around 30 per cent of Ceres’s mass. It is likely that in the past some of this water was liquid (perhaps heated by decaying aluminium). As this liquid moved around, it would have come into contact with layers of silicate material and would have altered them chemically. The extent to which this happened depends on where Ceres formed. If it formed in the colder, outer Solar System, the frigid temperatures would have meant the water was more restricted. That would lead to fewer signs of interaction between water and rock.

Wherever Ceres came from, there are recent clues that not all of its water is

constantly frozen. In early 2014, the Herschel Space Telescope spied a cloud of water vapour around the dwarf planet. It was the first time that water had been found in the asteroid belt. And wherever there is liquid water, thoughts inevitably turn to the possibility of life. A tantalising clue to the possible source of that water came in January this year as Dawn began its approach to Ceres. Images from the probe revealed a white spot on its surface. The same spot appeared in the Hubble images over a decade ago. Some researchers have suggested it could be a geyser that is shooting jets of water into space as heat from the Sun warms the ice. That would make it similar to Saturn’s moon Enceladus, which is known to be spewing water and is a heralded place to look for life in our Solar System.

So the stakes are high. Depending on what Dawn finds, we could look back at its arrival at Ceres as the first time the asteroid belt became a viable place to search for extraterrestrial life. This year could be a watershed moment in our understanding of planets. Not only is Dawn exploring Ceres, but later this year NASA’s New Horizons mission will arrive at Pluto. “We’ll start to get a much more nuanced view of the evolution of bodies in the Solar System,” says Raymond. “Rather than starting with stuff and ending up as a planet, we’re starting to see it more as a spectrum of stages in-between.”

We’ll soon know how Ceres and Pluto fit into that picture. What’s certain is that the dwarf planet debate is far from over.



Could the white spot on Ceres be a geyser?

COLIN STUART is an astronomy writer and co-author of *The Big Questions In Science*

DROWNING IN PLASTIC

More plastic than ever is finding its way into our seas, and a lot is sinking to the bottom. **Hayley Birch** finds out how we can get rid of it

PHOTO: ANGRYSUNBIRD/FLOCKR



Throwaway living took off in the second half of the 20th Century. Disposable coffee cups, plastic stirrers and parties where all the plates could be tossed in the bin ‘improved’ our lives. Global plastic production soared from 1.5 million tonnes in 1950 to nearly 200 million tonnes in 2002. Today, it’s reached the 300 million tonne mark.

Reports of ocean garbage patches suggest that much of that plastic eventually ends up in our seas. But the reality is much worse, says Marcus Eriksen, one of the co-founders of 5 Gyres, the organisation that studies plastic pollution in



➔ the seas. “We should look at these not as garbage patches, but as clouds of microplastics in the world’s oceans,” he says.

Microplastics is the technical term for tiny pieces of plastic. These are the remnants of throwaway living that have leaked into every ocean. Take a boat out far enough and you’ll witness – as Eriksen has – bottles, toy figurines, roller balls from underarm deodorants and thousands of plastic sandals all floating around in the sea. But microplastics are so finely shredded by ocean currents that they’re impossible to spot from a boat and are easily mistaken for food by sea creatures.

One of Eriksen’s recent studies, published in December 2014, suggests that at least five trillion pieces of plastic, altogether weighing in at over 268,000 tonnes, are floating around near the surface of the sea. An incredible 92 per cent of the pieces are microplastics. But these numbers don’t tally with the volume of plastic we’re producing. A second study published a week later explains why. While a lot of plastic initially floats, it soon gets clogged up with various kinds of gunk and ends up sinking to the seafloor. Just one handful of deep-sea sediment could contain up to 40 pieces of microplastic. At depth, this stuff is difficult to reach, let alone clean up. Which leaves us with one question: what are we going to do about it?

All at sea

A project called The Ocean Cleanup has been testing floating platforms for collecting bigger bits of plastic, but their own feasibility study suggests they cannot deal with microplastics. According to Eriksen, we’ll have to live with what’s already out there. “It’s going to sink, it’s going to get buried, it’s going to fossilise,” he says. “There’s no efficient means to clean up 5km down on the ocean floor.”

No one really knows what damage all that stranded microplastic is doing, but the hope is that once it’s mixed up with the sediment, it’s doing less of it. Yet the clouds of microplastics swirling in the water column pose a problem. The debris is easy for marine life to swallow, but the gunk that the plastics collect – such as pollution and bacteria – are also a threat. Plastics could be accelerating the passage of toxic chemicals into the food chain.

In May 2014, chemist Alexandra Ter Halle joined the Seventh Continent Expedition to the north Atlantic Ocean with the aim of analysing the gunk. After



The Seventh Continent Expedition with some of the rubbish they recovered



Ocean currents shred plastic into fine strands that are difficult to trace and even harder to clean up

“The difficulty is that there are so many plastics, of different colours, shapes and compositions”



Alexandra Ter Halle, from the Seventh Continent Expedition



A trash boom on Ballona Creek in Los Angeles catches plastic rubbish

Rogues' Gallery

The plentiful plastics in our seas



Sample of ocean water with visible particles of coloured plastic



The Seventh Continent Expedition found some huge plastic items



Nurdles

Millimetre-sized plastic pellets used for making plastic products are frequently spilled into the oceans during shipping



Fishing gear

Buoys and nets are long-lasting and common 'big plastic' finds. Animals often get entangled in them – this is known as 'ghost fishing'



Microbeads

Tiny beads used in toiletries are too small to filter from water. They enter the food chain when eaten by animals



Single-use items

Plastic bags, cups, bottles and forks are often not recycled and eventually end up in the sea



Shipping waste

Cargo ships dump – or lose – millions of tonnes of waste every year

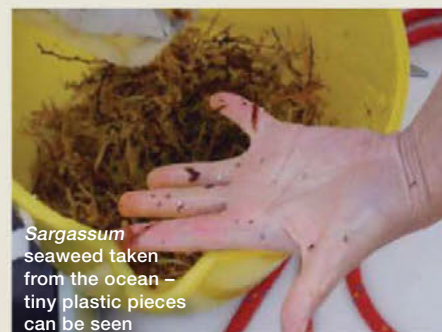


Fabric fibres

Washing machines send synthetic clothing fibres, such as polyester, into water systems



Strands of microplastics found during the Seventh Continent Expedition



Sargassum seaweed taken from the ocean – tiny plastic pieces can be seen

two days at sea, the boat was surrounded by thousands of small pieces of plastic. Ter Halle collected samples and is now analysing her data back at Paul Sabatier University in Toulouse, France. She is trying to work out why some plastics attract pollution as they age. "The difficulty lies in the fact that there are so many plastics, of different colours, shapes and compositions," she says. "It's difficult to extract a trend from all those pieces."

The various types of plastic aren't just a dilemma for scientists; they're also problematic for consumers and recyclers. How many times have you wondered into which box to put a plastic lid or some flimsy bit of packaging, then ended up trashing it because you weren't sure?

Nothing new

Ter Halle agrees there's no easy way of cleaning up the existing mess. The answer, instead, is prevention. She says that switching to biodegradable plastics could offer part of that solution. While the first generation of biodegradables just broke down into smaller pieces, the second generation may have some utility. Ter Halle suggests that they could, for instance, be handy for shopping bags.

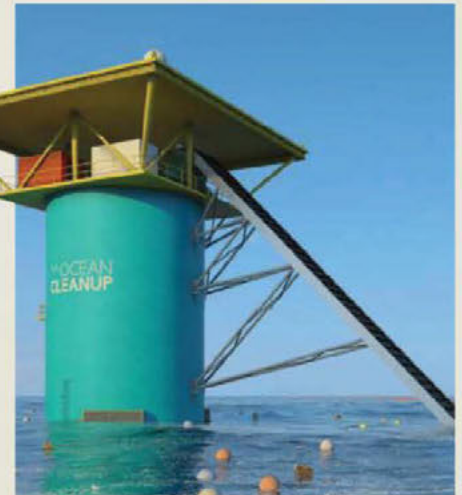
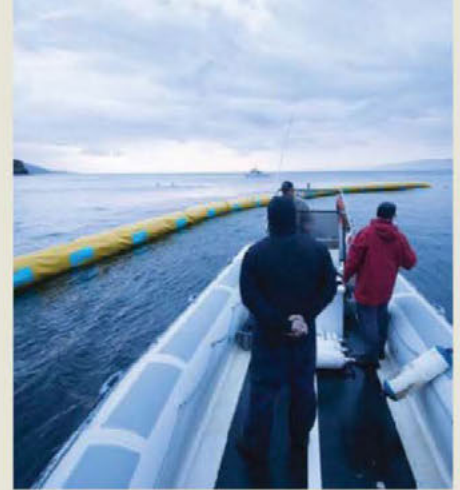
Yet Prof Richard Thompson, a marine biologist at Plymouth University, believes that the very notion of biodegradable plastic is flawed. "The idea that you could build into a plastic some kind of magic





PHOTO: 5 GYRES/Flickr X3, OCEAN CLEANUP X2, GETTY

Easter Island has a population of less than 6,000, yet plastic pollution is still found there



The Ocean Cleanup project (top and above) has been testing floating platforms to remove large pieces of plastic

so that it would fulfil its life in service without deteriorating and then, the minute it becomes an item of litter, it somehow rapidly and harmlessly degrades... it kind of seems like you're aspiring towards the impossible," he says. According to Thompson, another problem with biodegradable plastics is mixing them with other plastics as part of the recycling process. The lifespan of the final recycled product is shorter than a product containing no biodegradable plastic.

Closing the loop

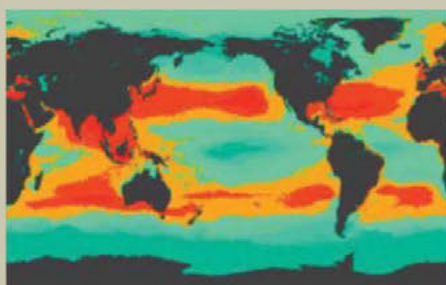
Thompson is one of the authors of the second December 2014 study. Having uncovered the true extent of microplastic pollution in seafloor sediment, he wants to see an end to plastic entering the ocean.

So does he have an answer? He recently attended a workshop in Portugal involving over 50 people from around Europe, including scientists, policymakers and industry types eager to offer ideas for solving the problem. But there was a shortage of cutting-edge solutions. "From my perspective, there was nothing new from any of the participants," he says. "A

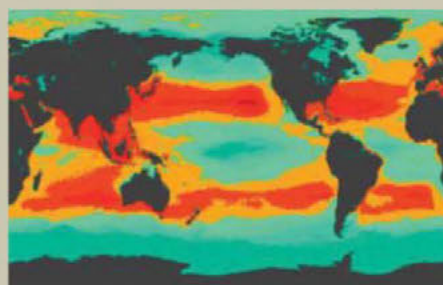
Map of Plastic Density

At least five trillion pieces of plastic are floating in our seas.

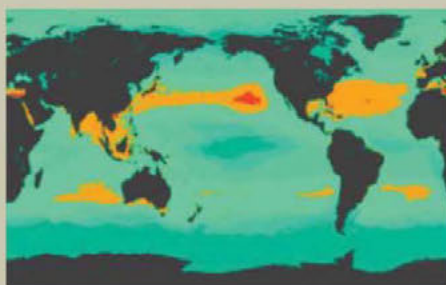
The majority are microplastics measuring under 5mm. These maps show the density of different sized plastics in each square kilometre of the Earth's oceans



Plastic size: 0.33 - 1.00mm



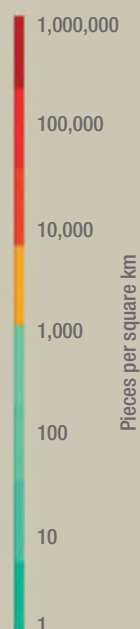
Plastic size: 1.01 - 4.75mm



Plastic size: 4.76 - 200mm



Plastic size: over 200mm



range of solutions are known to us, but it's more about translating that into action."

One option is banning certain types of plastics for particular applications, such as the plastic microbeads used in facial scrubs and toothpastes. These tiny particles – often measuring less than 1mm – wash straight down the sink and are too small to be filtered out at the waterworks. Thompson and Eriksen are both in favour of this approach, with 5 Gyres supporting a Beat the Microbead campaign that was started by the Plastic Soup Foundation. But it's not enough. Eriksen says that industry has got to be made to take responsibility for the way

it uses plastic. "Using it for single-use candy wrappers, [potato] chip bags or stir sticks is just not responsible," he says. "What I suggest is that if the producer or manufacturer cannot guarantee very efficient recovery of their product, like with some redemption programme or coupon, it had better be environmentally harmless."

To dramatically reduce the amount of plastic accumulating in the oceans, the 'loop' of producing and recycling plastics would have to become a closed one. This means that any material leaving the system as waste would enter it again as a renewable resource. All plastic products would need to

be designed with an end-of-life care package. In short, solving the plastic problem in the oceans means solving plastic pollution, full stop.

Thompson gives the example of two empty plastic bottles in his office. Both are made from the same recyclable plastic, but one is worth at least six times less than the other, just because it is red. Clear plastic is far more valuable to a recycler, but manufacturers don't think about this when they're designing their products.

We're still living the throwaway lifestyle we got excited about in the 1950s, but we have to make that our past.

HAYLEY BIRCH is a science writer and author of *The Big Questions In Science*

THE AGE OF THINGS

BY GILES SPARROW

Written history only stretches back a few thousand years, so scientists had to come up with techniques to help them establish the ages of fossils, rocks and remains from ancient times

For archaeologists, palaeontologists and geologists, working out the age of ancient materials is a crucial step to understanding their significance. Whether it's an ancient housing timber or a fossilised dinosaur bone, having an idea of its age is key to working out how an object fits in with its surroundings.

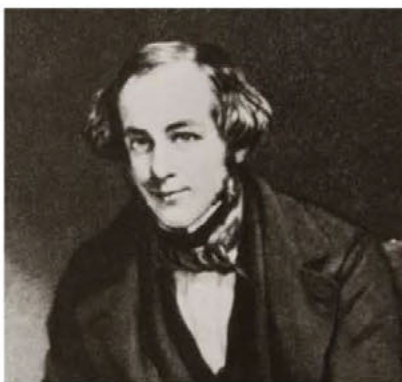
Working out the age of things is far from simple. For some relatively recent objects and structures, we may be able to tie them to written records. But our written history is a blink of an eye in comparison to Earth's long timespan. As a result, scientists studying the past must use a wide range of different techniques to date objects. These may provide a relative context by identifying which materials are older or more recent than others. Alternatively, they could provide an absolute date, either by combining archaeological information with historical records, or by using techniques that are rooted as much in the physics laboratory as they are in the dig site or library.

The most obvious means of dating objects is to attempt to put them in a context provided by historical documents. This was the thinking that sent archaeologists to the Near East in the

18th and 19th Centuries, hoping to dig up finds linked to the Bible and other ancient chronicles.

Match it up

One way of calibrating records from different civilisations using different calendar systems is to look for matches between recorded events – for example major military clashes, often involving specific rulers, that may have been noted by both sides. Astronomical phenomena can be even more useful. Chroniclers often recorded spectacular solar eclipses,



Archaeologist Sir Henry Rawlinson used records of celestial events to figure out historic dates

and these take place according to the inexorable laws of celestial mechanics. The precise dates of past eclipses can then be worked out in our modern calendar, giving precious fixed markers for ancient chronology. As early as 1867, British politician and archaeologist Sir Henry Rawlinson pinpointed an eclipse recorded in ancient Babylonian writings to 15 June 763BC. This date is now generally considered to anchor an entire strand of history dating back as far as 910BC, affecting not just Mesopotamia, but also Egypt and further afield.

But there are major problems with relying on written chronicles: only a limited number of events were considered worth recording, so it's rare for those to relate to specific archaeological remains. And even if they do, archaeologists have often discovered the hard way that chroniclers are not always accurate. A long-standing problem in Biblical archaeology, for example, is the lack of physical evidence for the 'Golden Age' of trade and construction that the Bible says happened in the Kingdom of Israel under King Solomon around 950BC. Spectacular finds led by analysis of historical records, such as the 2012 discovery of Richard III's remains





> IN A NUTSHELL

The 17th-Century Danish scientist Nicolas Steno is one of the founders of stratigraphy. His law of superposition stated that material is laid down in horizontal layers, with the oldest layers at the bottom. Even today, we still use Steno's principles. Rock layers can be clearly seen in the Grand Canyon, pictured here.



beneath a Leicester car park, are few and far between.

Archaeologists tend to avoid over-dependence on ancient historians. Instead, they rely on principles and techniques shared with palaeontology and geology. The most fundamental of these, written down by Danish scientist Nicolas Steno and published in 1669, forms the basis of stratigraphy.

Steno's law of superposition states simply that materials are deposited in horizontal layers, with the lowermost layers formed first. Barring any later disturbance, more recent material will always lie on top of older material. His

principles of original horizontality and lateral continuity are most significant in geology – they point out that strata (layered deposits within rock) initially form in horizontal layers, and will spread out widely over a surface unless some obstacle blocks their way. Finally, the principle of cross-cutting relationships states that features cutting across or otherwise disrupting a stratum must have formed after it.

For geologists and palaeontologists, Steno's principles help reveal the sequence of different rock layers and the fossil remains that may be embedded within them. For archaeologists, the same

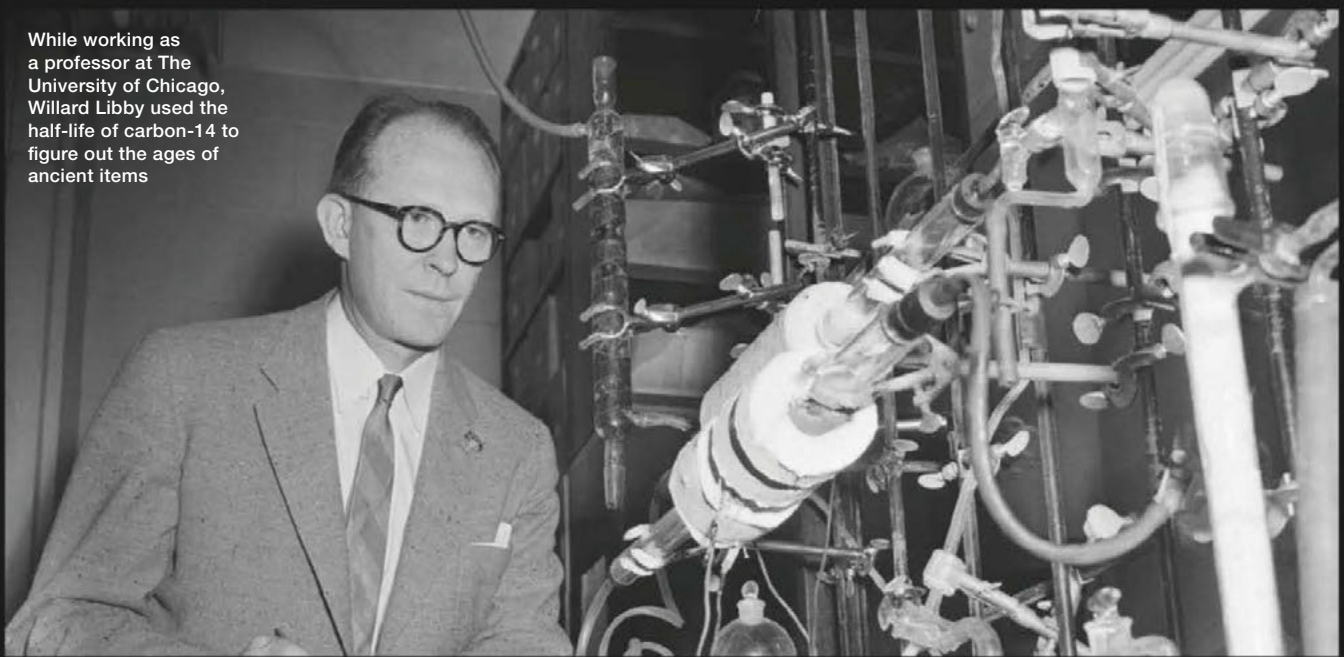
basic rules of stratigraphy can show the sequence in which different buildings or other human-related artefacts have built up over time. William Cunnington, a merchant and self-educated antiquarian, was the first to apply stratigraphy in this way from the late 18th Century, while studying prehistoric monuments in the English county of Wiltshire where he lived and worked.

Some archaeological finds come with their own dating information conveniently attached. Most plentiful of these are coins, which frequently name and depict the ruler who authorised their issue. Inscribed stones and other artefacts are rarer,

THE KEY EXPERIMENT

Willard Libby thought that carbon-14 was present in all living things. After proving this to be correct, he realised that the isotope could help establish the age of relics

While working as a professor at The University of Chicago, Willard Libby used the half-life of carbon-14 to figure out the ages of ancient items



In 1939, Willard Libby led an investigation at UC Berkeley looking at whether any of the elements common to organic matter might have useful radioactive isotopes that could be used in medical research. Using highly sensitive Geiger counters that he had developed, Libby established that carbon-14 (C-14) was far more stable than previously thought, with a half-life of 5,730 years. Working with colleagues, he subsequently

pinpointed its likely origin to cosmic rays interacting with atmospheric nitrogen. He formed the idea that C-14 might therefore be a natural component of all living organisms. The intervention of WWII meant that he was unable to pursue these ideas until 1945. Later, at The University of Chicago, he first established that his thesis was correct by comparing the radioactivity of sewage methane with that extracted from refined petroleum. He then

floated the idea that radiocarbon could be used for dating organic remains. In 1949, Libby and his colleague James Arnold tested the technique on wood from the tombs of two Egyptian pharaohs. They measured the current rate of radioactivity in their samples and delivered dates of around 2700BC, which matched up with those established by other methods. Libby was ultimately awarded the 1960 Nobel Prize for chemistry for this work.

but can be still more informative. But even then, the dates they provide have their limitations. Barring exceptional circumstances, artefacts can remain in use for long periods after their manufacture, so a coin found in an archaeological deposit only provides an 'earliest possible' date for an event.

Top of the pots

In the late 19th Century, English archaeologist WM Flinders Petrie made a huge advance in the study of historic objects. Through careful investigation of finds from a range of sites – at first in Egypt and later across the Near East – he identified different pottery styles. He then worked out the most likely sequence in which they had been introduced, become popular and fallen out of use. Pottery proved to be the ideal raw material for a new dating technique called 'seriation' because it has been cheap and widespread since the beginning of human civilisation. It is quite fragile, and is therefore more likely than precious coins to be broken and discarded shortly after manufacture, yet its individual fragments preserve well after disposal.

Petrie used the seriation technique for dating his excavations. He used simple strips of paper to record the range and frequency of pottery styles at certain sites, and shuffled them into what seemed the most economical, logical order. Throughout the later 20th Century, however, archaeologists applied increasingly rigorous approaches to seriation, including the 'Harris matrix'. This is a diagrammatic chart of finds and their stratigraphic contexts that was developed by Bermudian archaeologist Edward C Harris in the 1970s. They also used Bayesian statistics, which is a very powerful method for analysing the evidence for different hypotheses. This was invented by English philosopher Thomas Bayes around 1760, but only started to be applied in archaeology from the 1980s.

Most archaeological finds, however, come with no such convenient dating evidence. As scientists have found on many occasions, assumptions about the relative sequence of events in evolution or geology can turn out



CAST OF CHARACTERS

Five talented scientists who helped us establish the age of things

WM Flinders Petrie (1853–1942)

Petrie was fascinated by archaeology from a young age. He surveyed prehistoric sites as a teenager, before travelling to Egypt and making the first rigorous study of the Giza pyramids. Alarmed by the destruction of ancient monuments, he dedicated the rest of his career to preserving and excavating sites across Egypt and Palestine.



Nicolas Steno (1638–1686)

Steno was a Danish Catholic priest, and later bishop, with a fascination for the natural world. He laid down the laws of stratigraphy and made one of the first detailed studies of fossils, but wrongly concluded that they formed within the ground. He was the first person to identify the heart as a muscle.



AE Douglass (1867–1962)

US astronomer Douglass helped Percival Lowell establish his famous observatory at Flagstaff, Arizona, before splitting with him over Lowell's belief of canals existing on Mars. He first investigated tree rings as a means of mapping past cycles of solar activity, but realised they could provide a powerful dating tool.



Ernest Rutherford (1871–1937)

New Zealand-born Rutherford was a physicist who conducted research into radio waves and radioactivity. Working in Montreal, Manchester and Cambridge, he discovered the existence of the atomic nucleus, identified the three main types of radioactive decay and mapped out the 'decay series' of important radioactive isotopes.



Willard Libby (1908–1980)

Colorado-born chemist Libby spent his early career at The University of California, Berkeley. Here, he developed new forms of Geiger counter and identified intriguing properties of C-14. He became a professor at The University of Chicago, where he led a team that made radiocarbon dating a reality.



TIMELINE

Five vital steps that helped us start determining the ages of human artefacts, fossils and rocks



Nicolas Steno publishes his *Dissertationis Prodomus* or *Preliminary Discourse*, outlining principles of stratigraphy. These are still widely applied across the sciences of geology, palaeontology and archaeology.

1669

1898

While excavating the site of Diospolis Parva in Egypt, WM Flinders Petrie develops the ideas of pottery seriation in order to establish the relative dates of structures with no linking stratigraphy.



Bertram Boltwood identifies lead as the end-product in the radioactive decay of uranium, and subsequently uses the proportion of lead in uranium ores as a means of dating rocks.

1907

1919

AE Douglass applies the techniques of tree ring dating to establish the relative dates of several Native American sites across the American Southwest – the first archaeological application of his ideas about 'dendrochronology'.



Willard Libby publishes the first tests of his radiocarbon dating technique, opening the door for a revolution in the dating of archaeological remains.

1949



to be wildly inaccurate.

Fortunately, two discoveries in the 20th Century paved the way for a new range of dating techniques that are widely used today.

Ringing the changes

The first of these techniques was surprisingly simple – the variability of tree growth rings. Each year a tree is alive, its trunk lays down a distinct, concentric ring. Around 1906, US astronomer AE Douglass showed for the first time that the thickness of these rings depends on growing conditions for that particular year. He developed this principle into the highly accurate method of dating known as dendrochronology. The pattern of growth rings in any piece of timber from a specific region acts rather like a barcode revealing exactly when it was alive. By comparing numerous timbers of overlapping ages, it is possible to count back through the years from timbers with a known age. Of course, this technique can only be applied to wood, but becomes more powerful when used in conjunction with another 20th Century breakthrough – 'radiometric' dating.

While investigating the behaviour of radioactive materials at Canada's McGill University between 1900 and 1906, New Zealand-born physicist Ernest Rutherford discovered the statistical property known as 'half-life'. For a sample of any particular radioactive material, the time taken for half of the atoms or 'isotopes' within it to decay is constant. In other words, after this period, half the original material will remain. After two, a quarter would remain, and so on.

Rutherford thought that radioactive decay could be used as a means of dating rocks. Following his suggestion, US physicist Bertram Boltwood realised in 1907 that uranium's slow decay into stable lead would gradually increase the amount of lead within uranium ores. Using this idea, he dated a variety of rocks to between 400 million and 2.2 billion years old, vastly extending the known age of the Earth.

Natural radioactive decay happens on a huge range of timescales, from billions of years to fractions of a second.

NEED TO KNOW

A glossary of terms used in the dating of ancient artefacts

1 COSMIC RAY

Cosmic rays are not a form of radiation. They are high-speed particles released by the Sun and even more violent and distant celestial objects, and enter Earth's upper atmosphere from space. Here, they may interact with gas atoms, breaking down into lower-energy particles and triggering the transformation of nitrogen into carbon-14.

2 HALF-LIFE

Radioactive decay is an unpredictable process, but when enough radioactive isotopes are present, statistical laws can be applied: the half-life of any specific isotope is the average time that it will take for half of a sample to undergo decay. Depending on the isotope in question, half-lives can vary from billions of years to fractions of a second.

3 ISOTOPE

Isotopes are atoms of the same element with different masses. These arise from variations in the number of neutrons in each atomic nucleus. An element's isotopes have identical chemistry, but heavier isotopes can have unstable nuclei and will undergo radioactive decay in order to reach a stable form.

4 MASS SPECTROMETER

A mass spectrometer breaks down a small sample of material into its component atoms. It separates them using electromagnetic fields and measures their relative proportions. Mass spectrometers are useful for many types of radiometric dating since they allow the precise ratios of isotopes in a material to be determined.

5 STRATIGRAPHY

Stratigraphy is the study of the patterns in which rock layers and other associated materials are laid down. It is the key to understanding the formation of rocks and archaeological deposits. For older rocks especially, determining the true stratification of a site involves not just the study of mineral layering, but also the way in which fossils have been laid down.



A scientist removes a sample from a piece of bone for carbon dating

Most decay series used for radiometric dating are on the slowest of these timescales. Uranium-lead dating, for example, uses two different decay series with half-lives of 4.47 billion and 704 million years. Such techniques are less accurate for recent materials because the decay of any radioactive isotope is unpredictable over short periods of time – it can be hard to tell the gradual decline of the 'decay curve' from random variations.

It's a date

The best-known dating method of all allows us to date more recent materials to a high degree of accuracy – and what's more, it works directly for organic remains rather than rocks and minerals that may be associated with them. The technique relies on the fact that small quantities of a radioactive isotope called carbon-14 (so-called 'radiocarbon') are continuously created by cosmic rays high in Earth's atmosphere, and subsequently absorbed into the bodies of all living organisms. Carbon-14 (C-14) decays into nitrogen with a half-life of 5,730 years. While a plant or an animal is alive, its internal proportion of C-14 remains the same as that in the atmosphere. As soon as it dies, exchange with the environment stops and the C-14 begins to diminish.

Radiocarbon dating was invented in the 1940s by US chemist Willard Libby and has become a major tool in the archaeologist's armoury, as it's useful for dating human and animal remains

as well as timber. The C-14 present in the material can either be estimated by measuring its radioactivity with a Geiger counter, or more accurately measured directly by breaking the sample down in a mass spectrometer.

Radiocarbon dating is not without limitations. C-14's relatively short half-life means that for remains more than about 50,000 years old, dwindling quantities make precise dating increasingly inaccurate. Even more significantly, the proportion of atmospheric C-14 can vary over time, depending on levels of cosmic-ray activity. Samples of different ages can therefore begin the process of decay from different levels. This problem was first identified by Dutch physicist Hessel de Vries in the late 1950s, and scientists have since dedicated a great deal of effort to developing a 'calibration curve' that estimates atmospheric C-14 over the past 50,000 years. They do this mostly by comparing radiocarbon dates with those derived from tree rings and other evidence, using computer models and Bayesian statistics to analyse the most likely scenarios.

The search for more precise and versatile dating techniques for all kinds of materials is an ongoing challenge, but it must be faced in order to improve our understanding of the past – for our planet, prehistoric life and ourselves.

GILES SPARROW is a science writer and author. His latest book is *Mars*

CERN's CMS tracker
was completed in
December 2014



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SEARCHING FOR ANOTHER SMASH HIT

The Large Hadron Collider has been switched back on.
How will it extend our knowledge of the subatomic realm?

CONTRIBUTORS



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writer at *BBC Focus*

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BEYOND THE HIGGS
BOSON

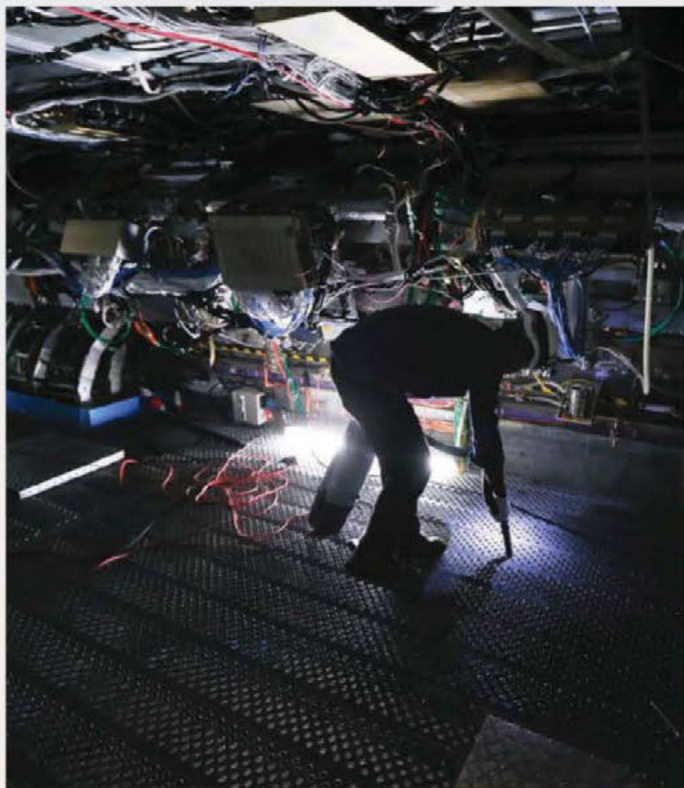


PHOTO: CERN X3

Top and above:
CERN workers
clean up the ATLAS
particle detector
ahead of the new run

Right: Technicians
prepare to insert
an additional
subdetector on the
ATLAS instrument

For those of us on the outside, it seems like there has been little going on at CERN since the announcement of the discovery of the Higgs boson in summer 2012. But although the Large Hadron Collider's (LHC) particle beam has been shut off since February 2013, things have been far from quiet beneath the Franco-Swiss border. Engineers and technicians have been busily repairing and upgrading the accelerator ahead of its next run.

The LHC is situated at CERN, in Geneva. It uses strong electromagnetic fields to accelerate charged particles, usually protons, around a 27km-long track at up to 99.9999991 per cent of the speed of light. Two bunches of particles are sent through the tubes in opposite directions, accelerated to the desired speed, squeezed into an area about one quarter the width of a human hair and then smashed together in dramatic collisions. It's an exercise in precision engineering that requires extreme attention to detail.

During the shutdown, 18 of the 1,232 giant (15m-long) dipole magnets used to bend the paths of the particles have been replaced. More than 10,000 electrical interconnections between the magnets have been upgraded. And the cryogenics system used to cool the superconducting magnets to temperatures of -270°C has been given an overhaul, as have the accelerator's complex electronics.

The upshot is that the accelerator will be able to run at higher energies than ever before, up from 8TeV (tera electron volts) to 13TeV. This is key in the search for new physics. As Einstein's famous $E=mc^2$ equation tells us, mass and energy are equivalent. When two high-energy particles smash into one another, some of their energy is converted into mass in the form of new particles. The higher the energy, the more mass there is available to create these particles.

Particles produced by the collisions are picked up by one of six detectors along the accelerator's track. The resulting data is pored over by researchers around the world, who look for signs of new science.

Read on to find out more about this incredible machine, the fundamentals of particle physics and the mysteries it could solve in the coming months. ➔





“Although the LHC’s particle beam has been shut off since February 2013, things have been far from quiet”

AROUND THE LARGE HADRON COLLIDER

Underneath Switzerland and France, the LHC's equipment generates a beam of particles to create high-energy collisions



1

LINAC LINEAR ACCELERATOR

The protons that are eventually smashed together in the LHC start out in a simple bottle of hydrogen gas. An electric field is applied to the gas to strip the hydrogen atoms of their electrons, leaving behind protons. These are injected into Linac 2, the first accelerator in the chain. From here another accelerator called the Proton Synchrotron Booster accelerates them further.



2

PS AND SPS

The Proton Synchrotron was the world's highest energy particle accelerator when it was first switched on in 1959. Now, the 628m-long machine accelerates protons ejected from the Proton Synchrotron Booster to 25GeV. Its younger sibling, the Super Proton Synchrotron, accelerates them to 450GeV before they're injected into the LHC proper, where they will reach energies of 13TeV.



3

LHC TUNNEL

The main tunnel housing the beam pipes is 27km in circumference and between 50m and 175m underground. For particles to pass unhindered, the pipes are kept in an ultra-high vacuum state that makes them as empty as interstellar space. The protons reach speeds of about 99.9999991 per cent of the speed of light, propelling them around the accelerator 11,100 times per second.



4

ATLAS DETECTOR

Beams of particles collide at ATLAS's centre, sending newly created particles in all directions. Six detecting systems, arranged in layers around the collision point, record the position and momentum of the particles so that they can be identified. ATLAS is the largest such detector ever made and measures 46x25x25m, about the length and width of an Olympic swimming pool.



5

CMS DETECTOR

CMS has the same general scientific goals as ATLAS but is built to a different design. It is based around a cylindrical coil of superconducting cable that can generate a magnetic field 100,000 times as strong as that of the Earth. The detector weighs as much as 10 double-decker buses and employs a workforce of more than 4,000 scientists and engineers from 41 countries.




6

MEYRIN CENTRE

Meyrin is home to a server farm the size of six tennis courts. It's the first point of contact between data from the accelerator and the Worldwide LHC Computing Grid. The Grid connects more than 170 computing centres in 40 countries, granting near real-time access to the 30 petabytes of data generated annually. That's enough to fill 6,300,000 DVDs.

THE STANDARD MODEL EXPLAINED

Over many decades, physicists have created a theory that explains what's inside atoms and the forces between them

 The Standard Model of particle physics helps scientists to classify fundamental subatomic particles and study nuclear interactions. No matter how hard we smash them together, these particles show no sign of having any internal structure. They are not made of anything else. And yet, everything else is made from them.

These fundamental particles can be classified in a number of ways, but probably the most important division is based on a property called 'spin'.

Particles that carry a whole number amount of spin (0, 1, 2 etc) are called bosons, and those that carry half-number amounts are fermions. All the 'matter' particles that make up atoms are called fermions. And particles that carry forces between the fermions are called bosons.

We can further separate fermions, the matter particles, into different types. One sub-class is the quarks. There are six varieties of quarks: up, down, strange, charm, bottom and top.

Quarks are combined into particles called hadrons. They are held there by the strong force, and that involves a huge amount of energy. This 'binding energy' is responsible for most of the mass of protons and neutrons: thus for most of the mass of atoms, and, therefore, of you. The boson carrying the strong force is known as the 'gluon'.

Quarks continually radiate and exchange gluons to such an extent that we never find a quark on its own – they are always confined inside hadrons.


The other class of particles is the leptons. The most familiar is the electron. When bound to a nucleus, electrons make up the rest of an atom. When free to move, they carry electric current and make our technology tick. The boson behind electricity, magnetism and the binding of electrons into atoms is the photon – the quantum of light.

For reasons not entirely clear, there are two copies of the electron: the muon and the tau. Just like the electron, these have a charge, but they also have more mass. This three-fold pattern mirrors that of quarks.

There is another kind of lepton, which has no electric charge – the neutrino. The only Standard Model force that neutrinos experience is the so-called 'weak nuclear force'. The quarks and other leptons also feel

this force, but because it is weak, it is usually hard to discern. Incredibly, we are continually bathed in neutrinos from the Sun (the weak force is vital in the fusion reactions that keep the Sun burning).

All fermions come with an antimatter partner: antimatter particles have the same mass but the opposite charge. And that's nearly it. Six types of quarks and antiquarks; six types of leptons and antileptons; and bosons carrying the electromagnetic force (the photon), the strong force (the gluon) and the weak force (W and Z bosons).

But there's more. Most of the mass of atoms comes from binding particles together. But the particles themselves have mass as well. Including their masses consistently in any theory presented a serious challenge. Back in the 1960s, Robert Brout, François Englert, Peter Higgs and others met this challenge in principle with the Brout-Englert-Higgs mechanism. This was then incorporated into the Standard Model over the following years. It requires the existence of a new quantum field, the Higgs field, which is present everywhere in the Universe, even in a vacuum. Interactions with this field give particles their mass, and the boson associated with the field, the Higgs boson, was discovered in 2012. This is the last piece of the Standard Model: its foundation, and its crowning glory. 

“When free to move, electrons make our technology tick”

Particle Zoo

A quick guide to subatomic terms

Fermions

Particles with a half-number of spin. These 'matter particles' make up atoms

Quarks

A sub-class of fermion. There are six types (up, down, charm, strange, bottom, top) along with antiquarks

Bosons

Particles with a whole number of spin. These carry forces between fermions

Photon

A type of boson that carries the electromagnetic field

Gluon

A type of boson

that carries the strong force

W and Z bosons

These carry the weak force

Higgs boson

This proves the existence of the Higgs field, which gives all particles their mass

Lepton

Another type of particle. The best known is an electron. Each has a corresponding antilepton

Muon and tau

These leptons are copies of the electron. They have a charge, but a lot more mass than the electron

Neutrino

A type of lepton. There are three varieties, which all have no electric charge

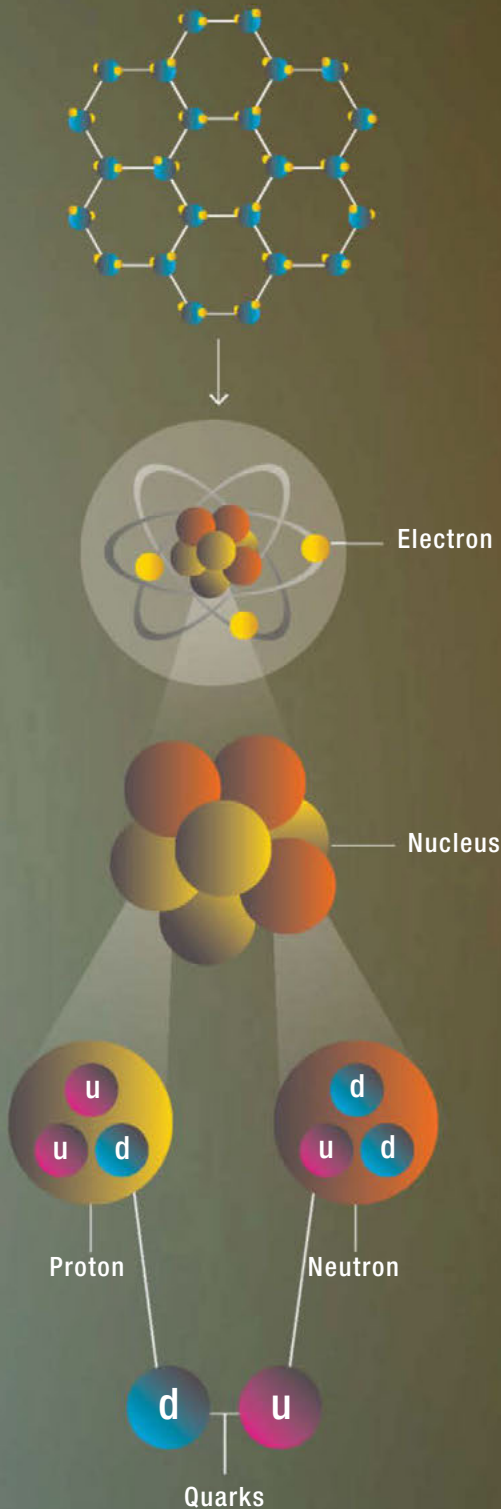
Spin

This is the angular momentum by which all particles are classified

FERMIONS

Particles that make up atoms

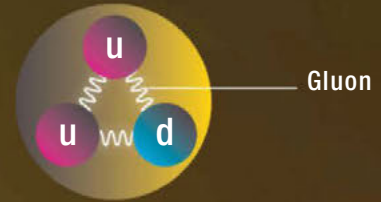
MATTER



BOSONS

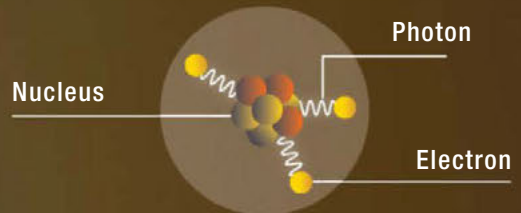
Particles that carry forces between fermions

STRONG FORCE



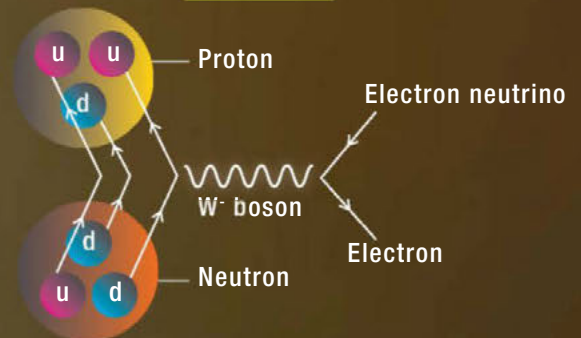
Gluons bind quarks to form hadrons, and hadrons to form atoms

ELECTROMAGNETIC FORCE



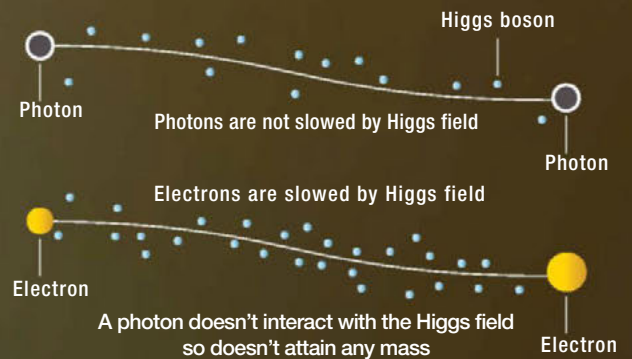
Photons bind electrons to atoms, and atoms to atoms to form molecules

WEAK FORCE



The W⁻ boson is involved in natural radioactivity such as beta decay, shown here

HIGGS FIELD



B E Y O N D T H E H I G G S B O S O N

After discovering the long-sought particle, what are scientists hoping to find this time around?

The Higgs boson was discovered using collision data recorded in the first run of the Large Hadron Collider, from late 2009 until the end of 2012. In spring 2015, after maintenance of the magnets, detectors and other infrastructure, collisions have started again at higher energy levels. What might we learn from the LHC's second run?

Experimentally, there are two main reasons why the new LHC data can take us further. The first is down to the quantum-mechanical, and hence probabilistic, nature of the processes we study. You might think that when two protons collide at a particular energy and angle, the results would be predictable, and always the same. In that case, if you have measured something once, why measure it again?

In fact, we can only predict the probabilities. A pair of colliding protons has many options open as to what it might produce. The Standard Model tells us how often to expect these various possibilities, on average, but it can't tell us how an individual collision will develop. This means that if we want to investigate rare possibilities, we need more collisions. It is as though we are trying to test whether a pair of dice is fair. The more times we roll the dice, the more sure we can be – and the more likely we are to spot any unexpected biases, which might be clues to missing elements in our knowledge.

M O R E H I G G S B O S O N S

Precise measurements will reveal how the Higgs field works

An especially important and rare 'side of the dice' is the newly discovered Higgs boson. Once produced in a collision, the boson decays almost instantly into other particles. And again, it has several options open to it, and the rates of the different decays are also subject to quantum statistics. Since the Higgs field gives particles mass, the rates that certain particles are produced in Higgs decays are predicted to depend strongly on their mass. Making precise measurements of this is vital to our understanding of how the mass mechanism really operates.

So far, we have clear observations of the Higgs boson decaying into photons and to W and Z bosons. Among the fermions,

only the tau lepton decays have been seen clearly, with some evidence of decays to bottom quarks. None of these measurements are very precise, and we would like to know more.

More data will also allow us to examine other properties of the Higgs boson more precisely – for example, how quickly does it decay? And is it even a fundamental particle, or might it contain the first clues to another layer of substructure? We would also like to see the Higgs interacting with itself, since this is how it is supposed to give itself mass, though that is a very difficult measurement.

There might also be heavier Higgs bosons out there just waiting to be found!

S U P E R S Y M M E T R Y

This could be the last chance for the LHC to find the predicted partners of the known particles

The second run will have more energy and that can help us learn more. We can potentially make new, more massive particles. It will give us improved resolution, allowing us to study the particles and forces more closely.

You might wonder why, since the Standard Model seems to be complete, we would even think there might be more particles out there. In fact, there are several excellent reasons to think that the Standard Model cannot be the final word.

For one thing, gravity does not fit. It is not included in the Standard Model or in any quantum theory. It is described by General Relativity, sitting somewhat awkwardly off to one side. Luckily, the effects of gravity on fundamental particles are weak enough that it can largely be ignored, for now at least. This means the Standard Model can hardly pretend to be a theory of everything.

There are also several apparently arbitrary features in the Standard Model. For example, as mentioned earlier, why are all the force-carriers bosons, and the rest fermions? By including the Standard Model into a larger theory, such arbitrary features can either be removed, or made an inevitable part of the larger structure.

One popular extension to the Standard Model is known as ‘supersymmetry’. Supersymmetry removes the arbitrariness between fermions and bosons, by introducing a fermion partner for every boson and vice-versa. They allow them to transform seamlessly into one another at high energies. The extra symmetry in these theories helps explain why the mass of the Higgs, W and Z bosons is low enough that we can actually study them. Without such extra symmetry, many theorists think the most natural value for these masses would tend to be very high – up to a billion billion times higher, near what is called the ‘Planck mass’. This is where gravity becomes so strong that it would have an effect in this tiny realm. It seems unlikely that the LHC will be able to help much with bringing gravity and the Standard Model together. However, the discovery of supersymmetric partners of the Higgs, or other particles, would be hugely exciting.

Supersymmetry predicts many new particles – partners for all the existing ones, plus three extra Higgs bosons. But the problem is that none of these have shown up yet. The second run at the LHC may be their last chance!



Left:
Supersymmetry allows particles to transform into one another at high energies

CLUES TO ANTIMATTER

Rare particle decays could explain why there's more matter than antimatter

There are four big particle detectors at the LHC. Two of them, ATLAS and CMS, discovered the Higgs boson and are general purpose detectors. The other two detectors are more specialised.

ALICE is optimised for those periods (usually a few weeks a year) when the LHC collides lead nuclei rather than protons. ALICE, ATLAS and CMS can all use such collisions to study exotic forms of matter, but ALICE has some unique advantages.

The final detector is LHCb, where the 'b' stands for the bottom quark. Many of these massive quarks are produced in the proton-proton collisions at the LHC. LHCb is specifically designed to detect as many of them as possible, and measure the different ways in which they decay to lighter particles.

Rare decays of particles like this are interesting for a number of reasons. For one thing, they can occur via tiny 'quantum loops', involving particles that are much too heavy to be produced directly. Measurements of such decays have already contributed to ruling out many possible new theories, including variants of supersymmetry. With more data in the second run, more theories

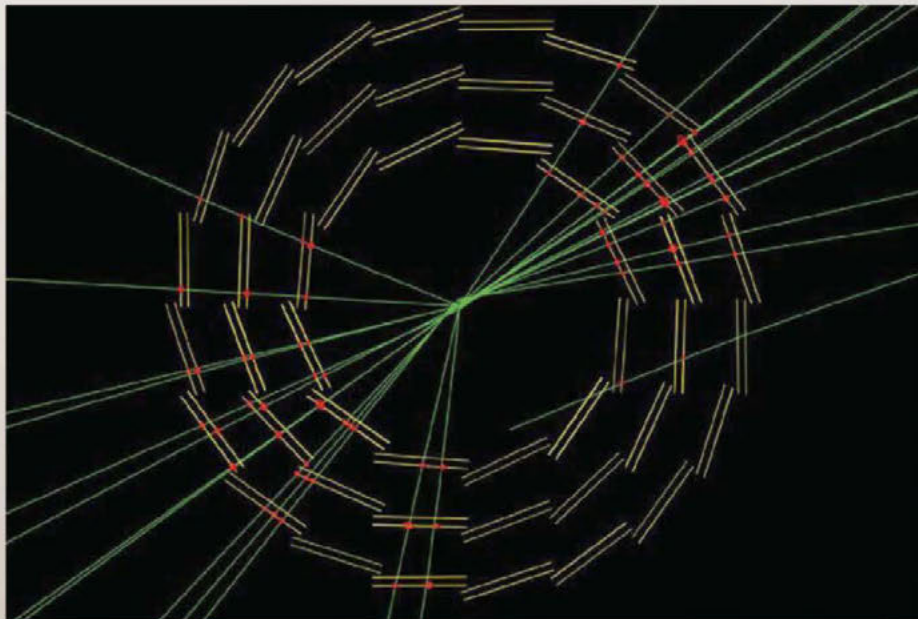
will be on the chopping block.

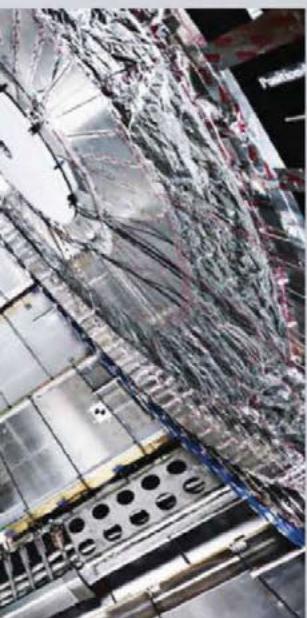
Decays of bottom quarks are especially interesting for reasons connected with the 'missing antimatter' in the Universe. In the Standard Model, particles and antiparticles are almost always produced in equal numbers – but the Big Bang seems to have left us with lots of matter and no antimatter. How? Where did all the antimatter go?

B-quarks are the heaviest version of the down quark (the strange quark lies between them in mass). Nobody knows why there are three copies of particles like this. But we do know that three is the minimum number for which it is possible to introduce some matter-antimatter asymmetry (known as CP-violation), into the theory. Measuring the b-quark decays is a very direct way to probe CP-violation, and LHCb has measured the effect.

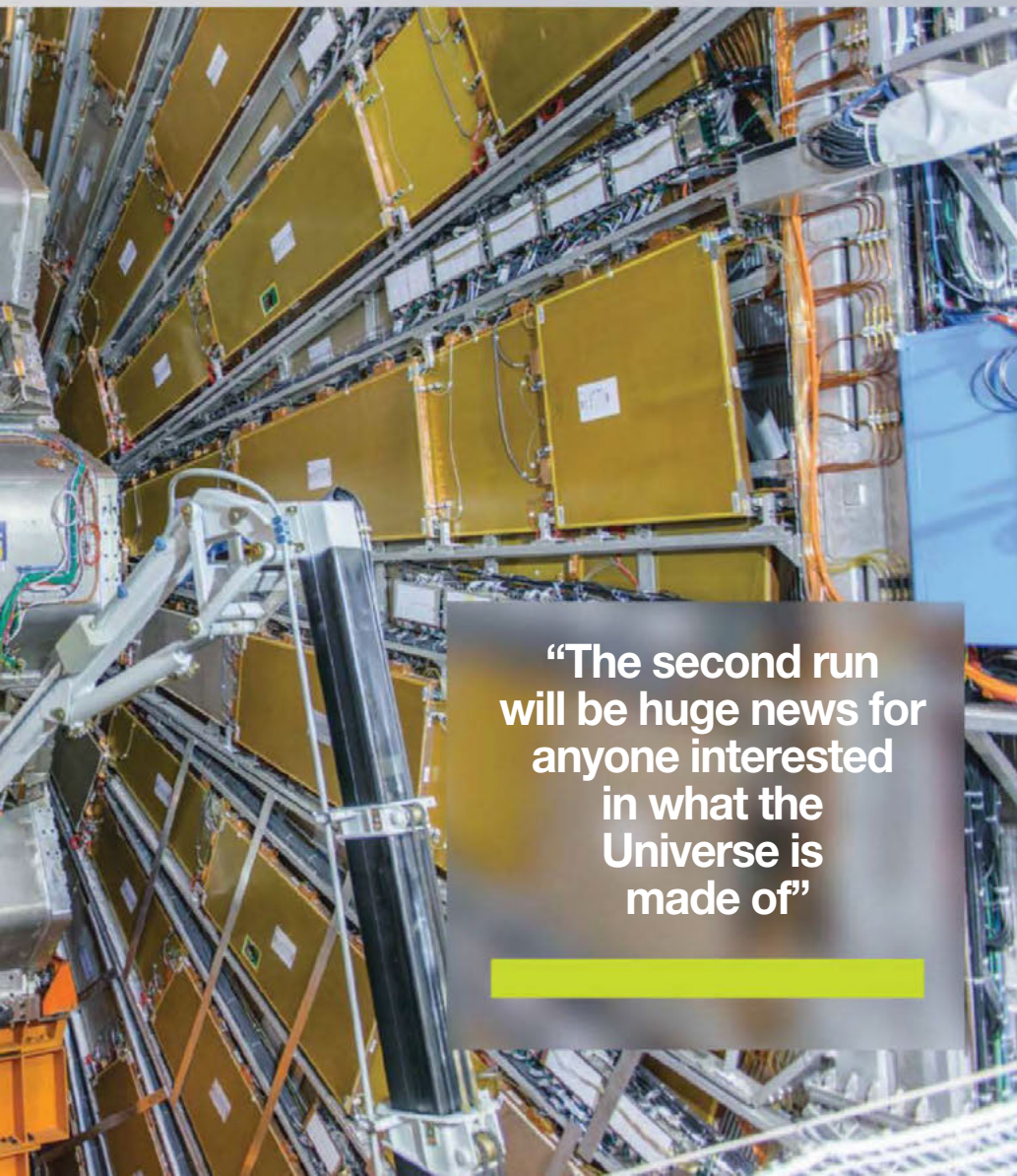
Unfortunately, the measured asymmetries do not seem to be big enough to account for the vast difference in abundance of matter and antimatter that we see around us. However, there is still more to learn here, and extra data from the second run will help increase our understanding.

Two particles annihilate forming a Z particle, which decays into a b-quark and antiquark





Along with the CMS detector, the ATLAS detector (pictured) found the Higgs boson



“The second run will be huge news for anyone interested in what the Universe is made of”

DARK MATTER

There's stuff out there we can't see, and the LHC might spot it

Another problem not solved within the Standard Model is the observational evidence that the Universe is filled with more matter than we can see. This is known as dark matter and does not seem to consist of any of the known particles. Far from 'everything else' being made of the quarks and leptons, astrophysical observations and cosmological models indicate that about 84 per cent of matter is something not contained in the Standard Model.

Supersymmetry suggests that dark matter could be a supersymmetric partner particle. If so, then there is a fair chance that we might actually be able to produce, and indirectly detect, pairs of dark matter particles in the new collisions. Several of the possible extensions of the Standard Model provide candidates for dark matter particles that might be produced at the LHC. In many of these theories, even if dark matter doesn't interact much with other particles, it still gets its mass from the Higgs field. Studying the Higgs boson (or bosons!) carefully is vital.

There are other experiments going on around the world that can tackle some of these issues too. Sensitive underground detectors are hunting for the glancing impacts of the dark matter particles that ought to be drifting past us all the time. High-energy cosmic ray experiments, other astrophysical observations, and precision measurements also have things to tell us. Perhaps most importantly, neutrino experiments are running or planned. And these could tell us whether the tiny mass of the neutrino comes via the mechanism proposed by Brout, Englert and Higgs, or by a more exotic route that involves it being its own antiparticle. Neutrino experiments will contribute to, or constrain, the possibilities for physics beyond the Standard Model.

The LHC is not the only exciting thing going on in particle physics over the next few years. But the second run will be huge news for anyone interested in what the Universe is made of.

EAGLE

isle

The isle of Harris has been described as the best place in Europe to see golden eagles. What makes it so good and what does it teach us about their behaviour, asks **James Fair**

Photos by **Laurie Campbell**



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With large eyes and retinas
that contain up to one million
light-sensitive cells per square
millimetre, golden eagles
have super-sensitive sight –
scientists say they can detect
prey from 1.6km away



In the airy kitchen of his self-built eco-house filled with Hebridean sunshine, Robin Reid is directing me to a birdwatching nirvana on his Ordnance Survey map. The RSPB conservation officer for the Western Isles points to Tarbert, on the isle of Harris, then follows the A859 with his finger, first west, then north as it snakes its way through the island's mountainous interior.

"You drop down to Loch Seaforth, where there's an outdoor centre, then there's a sharp bend and a car park," he says in an accent that blends his native Swedish with Geordie from his boyhood and the Scots of his home today.

The car park is at Bowglass – in Gaelic, Bogha Glas. By the standards of Harris, with its picture-perfect white sandy beaches, orchid-rich machairs and purple-heather moorland, it's an unremarkable location – especially for somewhere that Robin believes is the best place in the whole of Europe to see golden eagles.

"The track that goes up from Bowglass runs between four different golden eagle territories," Robin says, pointing to the footpath heading west. "If you spent a day between February and June going up that track, and you knew how to pick out the birds from 1km away – and the weather was half-decent – there's a good chance that you'd see five to ten different eagles. I can't think of anywhere else in Europe where you can walk up a glen and potentially see so many eagles in just three or four hours."

You've also got a chance of seeing a pair of white-tailed eagles that commute through the glen on the way to their hunting grounds out at sea, but for many visitors to Scotland golden eagles are the main attraction. They are perhaps more

representative of the country's mountainous topography and more symbolic of wilderness, and they thrive in the undisturbed interior of Harris.

There are an estimated 90 pairs of golden eagles in the Outer Hebrides – 20 per cent of the UK population of 440 pairs. Between 35 and 40 pairs live on Harris and south-east Lewis, and 22 pairs in a roadless, 500km² area of North Harris and south-west Lewis. On Skye, theoretically a more productive ecosystem, eagle density is a third lower.

Eagle heaven

"The Western Isles and Mull have the highest recorded density of breeding golden eagles in Europe," Robin says, citing three contributory factors. First, the heather-dominated mountain landscape supports the golden eagle's preferred prey species: mountain hares and red grouse. Second, because there are no driven grouse shoots – where there is a tendency to require large returns for high-paying clients – there is little history of persecution in the islands. The main field sports are deer stalking and fishing, neither of them affected by high numbers of apex raptors. Third, it has an expanse of good habitat that is unfragmented by intensive farming and ►

Above: a female eagle brings a mountain hare for her chick. Large prey is often 'prepared' away from the nest; she may have fed on the head before bringing the body

Below: the North Harris Trust's Matt Watts prepares to lead an 'eagle walk'. These take place in spring, summer and autumn, and attract up to 40 people at a time



"I can't think of anywhere else in Europe where you can walk up a glen and see so many eagles in just three or four hours"

Outer Hebrides

Bird of prey trail



Loch Stiapabhat

Local Nature Reserve

In winter flocks of wildfowl and waders attract white-tailed eagles, hen harriers (left), peregrines and merlin, as well as resident buzzards.

More details: <http://bit.ly/1AuTHVU>

Aline Community

Woodland

From the car park, follow the track down to Loch Seaforth. There are white-tailed and golden eagles here, as well as sparrowhawks in the woodland. More details: <http://bit.ly/1GUUHVc>

Bowglass (Bogha Glas)

From the car park, walk up Glen Vigidale for the chance to see 5–10 golden and white-tailed eagles in one day. Best in late winter and spring.

More details: <http://bit.ly/16vTF7a>



Committee Road

From the car park at the high point of Committee Road, look out over the moorland for hen harriers, short-eared owls (above) and merlin. This is one of the few places on the Uists where long-eared owls can be seen as well.

Rueval

This is the highest point (124m) on Benbecula, with a good track running from the A865 round its southern side. Watch for breeding hen harriers, merlin and short-eared owls, and golden and white-tailed eagles as you get close to the rugged east coastline.



Craigston

Follow the A888 for 5km west and north from Castlebay. Good for both merlin and golden eagles.



Ravenspoint

A visitor centre with café, hostel, shop and museum overlooks Loch Erisort, which is good for white-tailed eagles. Open all year.

More details: <http://bit.ly/1wI7IW8>



North Harris

Eagle Observatory

Golden eagles are most active in the spring, white-tailed eagles in autumn and winter. Also watch for merlin (right) at this spot a 2km walk from the car park.

More details: <http://bit.ly/1z15poK>

Beinn Langais

This 90m-high hill just off the A867 (10km from Lochmaddy, main settlement on North Uist) attracts golden and white-tailed eagles. In spring hen harriers, short-eared owls and merlin breed on the surrounding moorland.

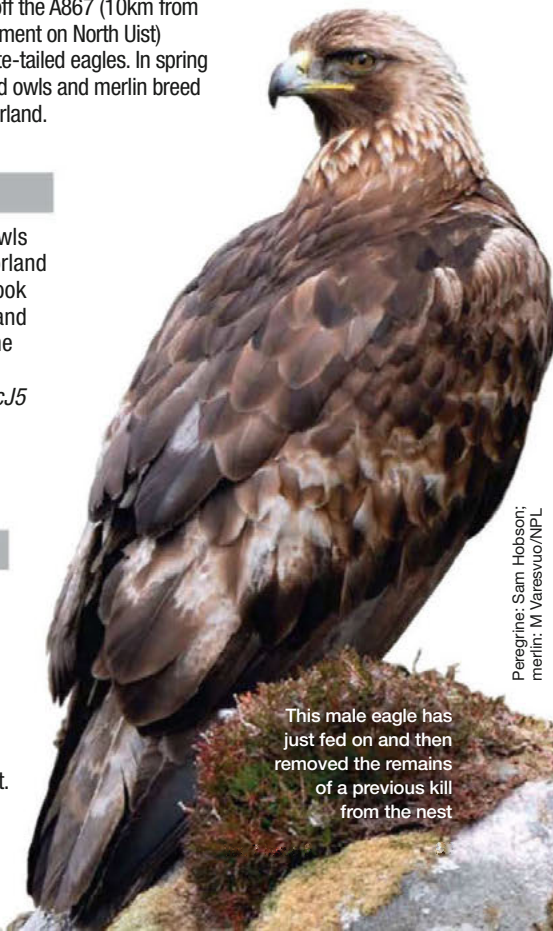
Loch Druidibeg

Hen harriers and short-eared owls breed in low-lying heather moorland at this large freshwater loch. Look for golden eagles to the south and white-tailed eagles following the shore as they cross the island.

More details: <http://bit.ly/1C5FcJ5>

Loch Sgioport

Look for white-tailed eagles on headlands and skerries at this sea loch 3km east of Loch Druidibeg. High ridges to the south attract golden eagles. Peregrines (left) are also seen on the coast.



This male eagle has just fed on and then removed the remains of a previous kill from the nest



Watch for soaring birds from the eagle observatory in Glen Miavaig on North Harris Trust land



The RSPB's Robin and Anna Reid ring and take measurements from a white-tailed eagle chick on Lewis



Above: a juvenile (note its streaky plumage) feeds on a deer carcass. Golden eagles rely more on carrion in poor weather

Below: in flight golden eagles often hold their wings in a shallow 'V', though it isn't always obvious

provides plenty of good nest sites, too.

"Another factor is the absence of foxes," Robin adds. "Here and Mull, but not Skye, are free from foxes [and always have been] and other mammalian predators. So the birds have everything – deer and sheep carcasses, hares, rabbits, grouse – to themselves."

Being half Swedish, Robin has a thorough knowledge of Scandinavia – but says that region can't rival the Western Isles for golden eagle sightings. "The open terrain here makes it a great place for watching birds," he says. "The heavily forested landscape in Sweden makes it impossible to see birds of prey, even though there are a lot of them."

On Harris, the eagles are largely left to get on with it. The North Harris Trust – a community-owned estate with the conservation of land and wildlife at the heart of its objectives – puts out deer carcasses in the winter, but that's it. Deer also have to be managed, but that's true in any part of Scotland. "If the deer density gets too high, the hills get over-grazed," trust ranger Matt Watts says. "That impacts on the habitat for grouse and hares, which in turn impacts on the eagles."

Golden eagles don't have Harris and the rest of the Western Isles completely to themselves, however. They face competition, but it's also airborne: the white-tailed eagle. This bird – which became extinct in the UK in the early

20th century before being reintroduced in the 1970s – has been steadily recolonising the Outer Hebrides over the past decade. In 2002 there were two pairs on Harris and Lewis, and one on the Uists. Today there are 25, and it's estimated that there's room for 50–75 pairs in total. But at the expense of golden eagles? Not necessarily.

The diet difference

The two species, though superficially similar, are essentially quite different (see box next page). Golden eagles are in the genus *Aquila*, but white-tailed (also called sea eagles) are *Haliaeetus* – the same genus as bald and Steller's sea eagles, more closely related to vultures and kites than 'true' eagles.

Compared with their mountain relatives, white-tailed eagles occupy a much broader niche. They will pluck a fish from a loch or the sea, scavenge a deer or sheep carcass, klepto-parasitise a seabird for its dinner or even eat the seabird itself. Golden eagles are hunters first, largely of mammalian prey, and scavengers second. Golden eagles nest in their hunting territory; white-tailed eagles usually nest close to a body of water, in a tree or a crag, and 'commute' to their food source. So the two species can live side by side.

Nevertheless there has been some disruption when white-tailed eagles invade their (distant) cousins' territory. "For the first few years after sea eagles establish themselves in an area, the breeding attempts of neighbouring golden eagles are often disrupted because they get caught up in interactions with the larger white-tailed eagles," Robin says. "Once the two species get used to each other, things calm down and they can co-exist."

With the launch of the Western Isles' Bird of Prey Trail, conservationists hope that the ease with which you can see eagles throughout the islands will attract more visitors. Laurie



Spot the difference...

How to know whether you're watching a golden or white-tailed eagle.



FACT FILE

Golden Eagle

Aquila chrysaetos

Range In UK, confined to Scotland, with one individual in England. Recently reintroduced to the Republic of Ireland.

Population Estimated at 440 pairs across Scotland.

Size Body length 0.8–0.93m, wingspan 1.9–2.25m.

Status Classified as 'Least Concern' by the IUCN.

FACT FILE

White-Tailed Eagle

Haliaeetus albicilla

Range In UK, Scotland; reintroduced to Republic of Ireland.

Population 90 pairs on the west coast and numbers increasing annually; 3 pairs established on the east coast.

Size Body length 0.9m, wingspan 2–2.4m.

Status Classified as 'Least Concern' by the IUCN.

Campbell, a wildlife photographer whose images accompany this article, says that this would benefit local people and the eagles, too.

"They have a saying up there: 'You can't eat the landscape'," he says. "A lot of crofters and hill farmers live on very low incomes, so it is a very marginal existence. It would be good if they saw the benefit of tourist money coming in." This would also offset any negative attitudes towards eagles that stem from a perception that they take lambs, though Reid says most lambs found in eagle nests have been scavenged rather than killed.

The pros and cons of having eagles in your back yard are hotly debated. A 2011 study found that white-tailed eagles on Mull attract up to £5 million of tourist spend every year, supporting as many as 110 full-time jobs. By and large, according to Mull's RSPB officer Dave Sexton, their presence is tolerated by farmers and gamekeepers.

Across the rest of Scotland, it's a different story. Without persecution the country could support between 500 and 600 pairs, according to Stuart Benn, the RSPB's communications officer for North Scotland – but up to 50 golden eagles may be illegally killed every year. Not only that, there is no reason why golden eagles couldn't live in many English lowlands, too, from East Anglia to the Somerset Levels.

"A few years ago I went on holiday to southern Sweden and Denmark, and it completely changed my attitude," he says. "Eagles were hunting rabbits and pheasants over arable fields – and, biologically, there is nothing to stop them doing that here. It's simply not true that they are purely a bird of the mountains – it's just that they've been driven there by human intolerance."

But if I want to see one for myself, Harris is clearly the place to start. However, during a morning at the North

"Scotland could support between 500 and 600 pairs of golden eagles – but up to 50 may be illegally killed each year"

Harris Trust's eagle observatory with Matt Watts, I draw a blank: the sunny, windless day merely brings out the midges. But surely such conditions should suit our eagles? "You want bright and breezy weather," Matt says. "If it's a flat calm and too hot, they'll do what they have to early on, then sit around for the rest of the day. Rain isn't a problem, but if the cloud's down then you won't see anything."

View to a kill

So, on Robin's advice, I head to Bowglass a few days later. The weather is more promising – high clouds, a spit of rain and a fresh breeze – and I soon hear the first throaty croaks of ravens, always a sign of something bigger in the sky. And, almost on cue, there are two eagles in my sights, skimming over the rocky ridge to my right.

Later, closer to the promontory of Tom Ruisg, I watch through binoculars as an eagle plummets earthwards, then lose sight of it among the rubble-strewn, heather-clad hillside. Thirty seconds later it's in the air again, and carrying something that resembles a sack of flour. The load is a mountain hare – I've just witnessed my first ever eagle kill.

Best place to see golden eagles in Europe? Who knows. But that's not a bad outcome for a gentle 1km stroll up a glen on a pleasant, breezy August afternoon.

JAMES FAIR is the environment editor of BBC Wildlife.



Symbiotic carnivores

The carnivorous pitcher plants found in the forests of Borneo have evolved incredibly intricate relationships with the species around them, says photographer and scientist **Christian Ziegler**



A slug crawls along the rim of a Kinabalu pitcher plant on Mount Kinabalu at approximately 2,900m. The plant is one of five endemic species here in the genus *Nepenthes*. Slugs are potential food for pitcher plants, but the plants can also offer useful habitat



BELOW RIGHT The flask-shaped pitcher plant *N. ampullaria* is a curiosity – it eats plants. The enzymes in its pitcher are best suited to digesting plant material, and the shape of the lid allows small twigs and leaves to fall in

FAR RIGHT A side view into a pitcher of a Rajah's pitcher plant *N. rajah*. A rich ecosystem forms around the nutrients in the shrew and rat excrement in the pitcher, which is composed of mosquito, fly and beetle larvae

The tropics can be freezing cold, if you climb high enough. But it's worth the chill to enjoy incredible views over the north-western part of the island of Borneo. I am hiking towards the summit of Mount Kinabalu, which at 4,095m is the highest peak in South-East Asia. Kinabalu's forested slopes reach down to tropical lowland forests, but up here, at about 3,500m, a stout, shrubby-looking 'elfin forest' no taller than 7–8m clings to the mountainside, ever windswept and often drenched by the rain.

Mount Kinabalu, especially its higher elevations, is also the epicentre of diversity for Asia's carnivorous pitcher plants. This group of some 150 species in the genus *Nepenthes* is spread across the continent with a couple of species reaching as far as Northern Australia and Madagascar. Five of the more than 15 *Nepenthes* species on the mountain are endemic – they are found nowhere else on Earth. Like all of the carnivores in the plant kingdom, pitchers have evolved in very wet, often boggy, environments. Access to nutrients such as phosphorus and nitrogen is very limited in such habitats, so the ability to generate your own 'nutrient income' by capturing and digesting organic matter provides a massive ecological advantage.

For a long time scientists believed that every type of pitcher plant trapped and digested insects in their variously shaped and sized pitchers. However, it turns out that pitchers engage with a vast range of animals in a variety of ways – all with the goal of obtaining a nutritional edge in a very challenging environment. Some animals in turn have evolved to exploit these pitchers as a resource. As researchers explore more and more of these exciting plant species, we can be sure that they will uncover many more surprises.

PHOTOS BY

CHRISTIAN ZIEGLER



Christian is a photojournalist specialising in natural history. A tropical ecologist by training, he has worked

extensively in rainforests on four continents, and since 2001 has been associate for communication with the Smithsonian Tropical Research Institute. Christian also participates in educational initiatives. He lives on the edge of a rainforest in central Panama. www.naturphoto.de



THE LOCATION

KINABALU PARK

Most of the images in this Photo Story were taken in Kinabalu Park, which is located on the west coast of Sabah in the north of Malaysian Borneo. The national park covers 754km² surrounding Mount Kinabalu, and is a World Heritage Site. Kinabalu Park contains a wide range of habitats and is a biodiversity hotspot with more than 4,500 species of flora and fauna.





The Endangered Rajah's pitcher plant *N. rajah* is the largest in its genus, containing as much as 3 litres of liquid. Its lid has nectar glands that attract the tree shrew *Tupaia montana* (pictured) and nocturnal rats. The small mammals often defecate and urinate over the opening of the pitcher – a valuable source of phosphorus and nitrogen





Worker carpenter ants *Camponotus schmitzi* pull a dead grasshopper out of the liquid of a pitcher belonging to a fanged pitcher plant *N. bicalcarata*. Such a large prey item would overwhelm the plant's digestive abilities and cause it to rot



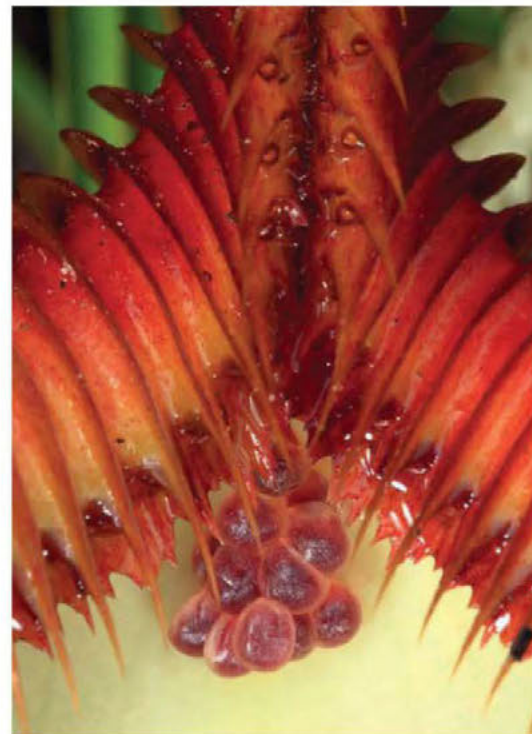
Hardwicke's woolly bat
Kerivoula hardwickii uses the
pitchers of *N. hemsleyana* as
a day roost. This is a beautiful
example of symbiosis – the
pitchers' shape and very
shallow filling of liquid allows
the bat to sleep in it without
drowning, while the mammal's
excrement supplies welcome
nutrients to the plant





The fanged pitcher plant
N. bicalcarata is found
in lowland peat forests in
northern Borneo. Some
animals have evolved to
use its pitchers as a home
and hiding place, such as
this small land crab





ABOVE A slug has deposited its drought-sensitive eggs in a large pitcher of the villose pitcher plant *N. villosa* found at about 3,100m on the slopes of Mount Kinabalu

BELOW This cross-section of a stem of the fanged pitcher plant *N. bicalcarata* in Brunei, north-west Borneo, shows carpenter ants *Camponotus schmitzi*. The plant provides a home to a small colony of ants (up to 30 or so individuals), which keep the chemistry of the pitcher liquid balanced

ABOVE Pooled water is rare along the very steep slopes of Mount Kinabalu, so it's no wonder that a few species of frog use pitcher plants as spawning grounds. They have evolved an immunity to the plants' digestive liquids so that their tadpoles can develop in them. This photo shows a fringed pitcher plant *N. tentaculata*



The Future Of Gadgets

TECHHUB

Edited by Daniel Bennett



On The Horizon

HoloLens

Holographic
computer
platformmicrosoft.com/microsoft-hololens

words: daniel bennett

The physical and virtual worlds are about to collide. Microsoft's latest research project, the HoloLens, wants to liberate your software from the screen and let it roam around in the real world via a pair of specs. Imagine popping on your HoloLens and then building a virtual *Minecraft* castle on your desk. That's the experience it could create.

The potential of the HoloLens doesn't just lie in gaming. The idea is that all the apps that currently sit behind your display could climb out into the real

world. In Microsoft's demo, a designer moulds the curves of a superbike with his hands; a dad gives his daughter virtual instructions to fix her sink; and a scientist explores Mars.

At first sight, the technology seems too fantastical to be real, and it wouldn't be the first time a tech company made promises it couldn't deliver. Closer inspection, however, reveals that the HoloLens simply blends existing technology to create something new.

First, the glasses use a prism projector (like Google Glass)





The HoloLens could allow users to build virtual 3D objects

➔ to create images directly in your field of vision. Second, Microsoft's own Kinect tech allows the headset to see, and make sense of, the world around it. Just as with Kinect on the Xbox, it follows your arms and hands, and translates this into instructions to the computer. By pairing these technologies, the HoloLens can recognise a flat surface and create a three-dimensional image in front of you. And then there's the sound.

For a virtual object to feel truly real, it needs to create noise, and that audio has to come from the right direction. The headset is fitted with special earphones and software that can simulate noises in a 3D space. This is crucial for immersion, especially since Microsoft hopes that the HoloLens will be used for simulations.

So far, so sci-fi. But there is a drawback. While all this technology does exist and can be fitted together, it's all rather large. The official imagery shows Microsoft's aspirations for the final product, but the

prototype is very different in reality. The first developers to wear the HoloLens (at Microsoft's secret basement laboratory) described wearing numerous straps, screws, battery packs and even fans that cooled the whole unit down. But every great idea starts with a cobbled-together prototype. Screens, batteries and processors are shrinking by the day, so there's very little to stop Microsoft putting together a finished device – closer to their concept imagery – within the next two years. And there's one very good reason for that.

That reason is Windows 10. Microsoft says it will build HoloLens compatibility into its next big operating system, which is something of a lifeboat for a company that has been losing users for the last few years. On top of that, the head of the project is the same Microsoft employee who delivered the Kinect technology that first blew us away five years ago. There's no reason why they can't do the same with the HoloLens now.



Microsoft's HoloLens concept cleverly blends existing technology

DANIEL BENNETT is the reviews editor of *BBC Focus Magazine*

Techometer

What's Hot

Yourview

This on-demand TV service pools together catch-up TV from BBC iPlayer, ITV Player, Demand Five and 4oD. Later this year it will be available on Sony internet-connected televisions as a single app. This service, which you can get already via set-top boxes, gathers together all of the week's TV that's online. It then puts it onto your episode programme guide, so you can simply scan over the past week to pick up any shows that you've missed.

youview

What's Not

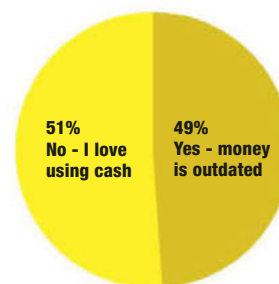
Keyless Car Entry

Walking up to your car and opening the door without taking out your keys is a neat trick, but it's one that car thieves seem to like too. A report published by London's Metropolitan Police suggests that keyless car theft is on the rise. In the capital, 17 cars are stolen every day without keys. Of these, 70 per cent are models that use keyless car entry. Apparently, the thieves have devised processes that can hack the car's entry system.



Reader Poll

Would you like a cash-free society?



The Next Big Thing

A Cash-Free World

Well, it seems that 2015 might be the year that we finally wave goodbye to cash. I already use contactless payment cards much of the time. I'm on the verge of abandoning my Oyster Card, which I use to pay for tubes and buses while travelling around London, since I can now use a contactless debit card instead. I also use my smartphone to pay for stuff – I've installed an app for one well-known coffee chain so that I can accumulate gold stars and get free coffee. And when Apple Pay comes to the UK, I'm sure I'll find myself using it. The days of paying with cash, handing over a note and receiving a pocketful of 'shrapnel' as change are numbered.

I'm not alone in changing my spending habits. The Payments Council, which looks at the whole range of payment services in Britain, is predicting that cashless payments will overtake cash transactions during 2015. And the trend is only going one way – not only in the UK but around the world too.

There are lots of different reasons for the move to cashless payments. One is simply that the technology is

now available to replace cash with other forms of payment, and the banking system likes this. Payment service operators such as Visa and Mastercard would like to see the end of cash, partly because it makes them money but also because they see it as a legacy technology. The CEO of Mastercard, Ajay Banga, calls cash "the dirtiest secret of the modern economy" and says that it is 200 years out of date. Plus, the cost of making coins and notes and moving them around is substantial.

There may also be political pressure to move away from cash. Electronic money expert David Birch argues that the two groups who like cash the most are criminals and tax avoiders, and that replacing cash would increase tax revenues and reduce corruption.

The change isn't just happening in developed countries either. Mobile payment systems like M-Pesa, which started life in Kenya, continue to grow in importance, not least because cash is very inconvenient if you live in a country with poor transport systems and few bank accounts.



As we move away from using cash, we are also going to see big changes in the forms of 'money' that we use to pay for things, or get paid for our work. Peer-to-peer digital currencies like BitCoin, independent of the banking system and the world's governments, continue to attract attention. Even if they won't ever replace the global financial system, they can still

serve as an alternative means of exchange for those who want to avoid the fiat currencies that are created by central banks.

Either way, you might want to hold on to your pennies – they might not be around for long.

BILL THOMPSON contributes to news.bbc.co.uk and the BBC World Service

From The Lab

What is it?

Scientists at the National University of Singapore have developed a flexible, nano power generator that produces an electric charge when it comes into contact with skin. It is the size of a postage stamp and creates 90V of energy and 0.8 milliwatts of current – enough to run a small wearable.

Gadgets powered by people

How does it work?

It relies on something called the 'triboelectric effect'. This takes place when a charge builds up between two dissimilar surfaces when they are put in close contact. It is this that causes your hair to stand on end when you rub a balloon against it. The generator collects this electricity to power a small device.

This sounds exciting. When Can I Get One?

The team's next goal is to build an activity tracker that is powered by the user's own motion. Perhaps in a couple of years we may see fitness watches that never need to be plugged in, allowing you to take them on holiday without lugging chargers and adaptors along with you.



The generator could lead to fitness monitors that don't need to be charged



ULTIMATE TEST

SOLID SOUNDS

If you're anything like us, your earphones go wherever you do, so they ought to be built to last. **Russell Deeks** tests the toughest in-ears in town...

Whether you're a sporty type or just a clumsy commuter, you don't want to spend good money on a pair of earphones only for them to break. So we took four 'rugged' pairs and put them through their paces. In our Snag Test, we caught the cable on door handles, many times

over. In the Jerk Test, we ripped jack from socket as roughly as we could, from every tortuous angle we could think of. The Shower Test is pretty self-explanatory, while our Crunch Test assessed their ability to withstand being trodden on by 13 stone of great lumbering oaf. Turn over to see how they fared...



SE215
SHURE

Shure has a long pedigree when it comes to pro audio equipment. This is evident in the build quality of these earphones, which Shure says are “built to withstand the extremes of on-stage or everyday wear”. They feature a replaceable cable, just in case it decides to break. However, as said cable is very substantial, Kevlar-reinforced and features an L-shaped connector, that’s frankly unlikely to happen.

The SE215 earphones are supplied with a choice of six different sleeves – three in silicone, three in foam – to help you get the best fit, therefore ensuring both optimum sound quality and maximum isolation. A pick for cleaning off any wax

build-up is also supplied, as is an oval carry case to keep them safe in your bag or pocket.

As for the sound quality, Shure’s pedigree once again shines through. Mids and highs are clearly defined, and there’s plenty of hefty bass that never sounds muddy or muffled. The stereo imaging could perhaps be a little better, but were we looking at sonic performance alone, Shure would likely be walking away with the gold here.

Sadly, they fell down a little in the toughness stakes. They handled the Jerk, Shower and Snag tests perfectly... but being stepped on was the straw that broke the Shures’ back.

shureasia.com



ATH-SPORT3
AUDIO-TECHNICA

The ATH-SPORT3 earphones feature an ‘ear-hanger’ design that ensures they’ll stay on your lugholes, and come with seven different sleeves to guarantee they fit nicely. Four of these are in plain silicone and three in ridged ‘active fit’ silicone. The latter are designed to let in more external sound so that they can be worn safely when jogging on city streets, for example. There’s a compact nylon case to keep them safe, too. The cable seems a tad flimsy, but it does feature an L-shaped connector and an attached clothing clip to prevent it from catching on things. Oh, and the earphones are water-resistant to IPX5, which means they’re splash-proof and can be safely used in

very humid environments.

This bespectacled, long-haired reviewer found the ear-hanger design a bit awkward at first, but you soon get used to it, and there’s no faulting their sound. They’re not quite as powerful at the bottom end as the Shures, and are a bit more brash, but the stereo imaging is better. Dramatically panned sounds actually sweep from one side to the other, rather than just suddenly popping up in the other ear. They passed our durability tests with flying colours, too.

All of which is particularly impressive when you look at the low price tag. If you’re on a budget, these are a great choice.

audio-technica.com



SPORT PULSE WIRELESS

JABRA

The hefty price tag of these earphones reflects the fact that they're not just earphones. They also feature a built-in heart monitor, which works alongside a dedicated Jabra Sport Life app – or other popular fitness apps such as RunKeeper – on your iOS or Android device.

The Jabra Sports also come with a choice of four sleeves and four different 'ear wings' to help ensure a close, comfortable fit. A no-brainer for sporty types, then? Er, not quite. Maybe I've just got weird ears, but despite trying every possible combination of sleeves and wings and watching a tutorial video on the Jabra website, I couldn't get them to sit comfortably at all. And because they weren't fitting tightly, the

sound coming out of them was almost entirely bass-free.

They're not without their good points: Bluetooth pairing is a doddle, with a woman's voice talking you through the process in the earphones themselves (a very snazzy touch), and with a useable range up to around six metres. They also work via NFC, which may be a bonus for some.

The hardshell black and yellow carry case looks really good and feels sturdy, and we couldn't manage to break the earphones even when we subjected them to a simulated downpour. But 'try before you buy' would be our advice here.

jabra.com



SUPERDARTS TITANIUM

ATOMIC FLOYD

These are the most expensive earphones in this test, but you certainly feel like you're getting your money's worth. Everything about them screams quality, from the sturdy, fabric-encased cable to the textured titanium casing used on the buds, the 3.5mm jack plug and even the Y-junction where the cable divides in two. There's an inline remote (also titanium), as well as a choice of four sleeves (three silicone, one foam). You also get a round rubber carry case and a two-pronged flight adaptor.

The fancy ergonomic styling preferred by rivals is eschewed in favour of a simple bullet design, but they're still extremely comfortable to wear and almost impossible to shake loose. And

they sound as good as they feel. They're a little on the bright side, maybe, so they're perhaps not the best choice for serious bass fiends, but definition is crisp and clear right across the range, and they impressed on the stereo imaging front.

What's more, they took all the rough punishment we could throw at them and still came up smiling. As we said at the start, they're not cheap by any means – but we can't see anyone ever regretting buying them.

atomicfloyd.com

RUSSELL DEEKS is a technology and music journalist, and editor of *Songwriting* magazine

QA

YOUR QUESTIONS ANSWERED

BY OUR EXPERT PANEL



SUSAN BLACKMORE

Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*



DR ALASTAIR GUNN

Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester



ROBERT MATTHEWS

After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University



GARETH MITCHELL

Starting out as a broadcast engineer, Gareth now writes and presents *Digital Planet* on the BBC World Service



LUIS VILLAZON

Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

editorial-bbcknowledge@regentmedia.sg

Q

How can you 3D print a person?

A Pictured Here is Andreas Kroker, a customer of German 3D-selfie firm TWINKIND. To produce such a 'mini me', the subject stands in a large 3D scanner. An assembly of high-resolution cameras instantly captures over a hundred images of the person from multiple angles. On the computer, the subject can be viewed in 3D, rather

like in the movie *The Matrix* where Keanu Reeves appears suspended in time. Then comes a process a bit like Photoshopping, but in multiple dimensions. A technician tweaks the digital 3D model to remove any blemishes or errors from the scanning process and

to touch up the image. Then, a specialist industrial grade 3D printer builds up the figure by spreading coloured powder in layers. As it goes along, a precise inkjet applies a binding polymer to hold it all together. The printer combines uncanny accuracy with pretty impressive scale, offering prints up to 35cm tall. **GM**

TWINKIND's 3D printers create perfect replicas of individuals – Andreas Kroker's 'mini me' is on the left



PHOTO: CORBIS

In Numbers

8.8cm

is the length of the longest nose on a living human. The measurement was taken from the bridge to the tip

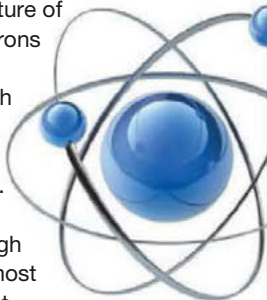
Why do we laugh when tickled?

A Tickling affects the same unmyelinated nerve fibres that carry pain signals, and our most ticklish parts are vulnerable spots, such as our neck, abdomen and armpits. Laughing for joy, amusement and tickling all activate brain areas controlling facial and vocal reactions, but only tickling activates the hypothalamus, which is an area that anticipates pain. It's possible that tickling is interpreted as a threat and the laughter is a social signal of submission to prevent us from getting hurt or to defuse a scary situation. **SB**



Why is there so much empty space in an atom?

A The simple picture of an atom is of electrons whizzing around a central nucleus with nothing in-between, but this is quite misleading. Quantum theory reveals that although the electrons are most likely to be found at specific distances from the nucleus, the supposedly empty space around them is seething with so-called 'virtual particles' constantly popping in and out of existence. **RM**



What makes us trust some faces over others?

A Simple facial features will contribute to how much we trust someone. Experiments show that faces with higher inner eyebrows, pronounced cheekbones and a wide chin are judged as more trustworthy. The amygdala, a structure associated with fear and other strong emotions, can respond to a face within 33 milliseconds (three-hundredths of a second).

Volunteers were shown both real and computer-generated faces for such short periods that they did not consciously see them. Nonetheless, they could still make judgments of trustworthiness. This high-speed assessment makes sense in evolutionary terms since detecting threats or judging strangers as dangerous could be crucial to survival. So we should not be surprised if we get a feeling about someone before we've even recognised them. Even so, we should be wary. There is little evidence that people with high cheekbones and eyebrows really are any more honest. **SB**

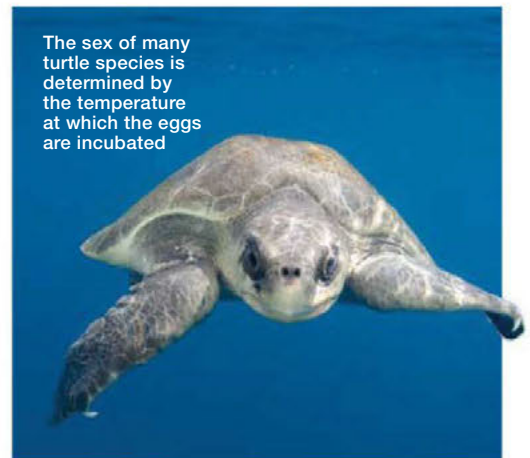


We wouldn't trust a bloke with half a beard, no matter how high his cheekbones were

How is the sex of some species determined by temperature?

A Temperature-dependent sex determination is seen in most turtles and all crocodiles and alligators. The mechanism isn't well understood, but one piece of the puzzle is the enzyme aromatase, which converts the male hormone testosterone into the female hormone oestrogen. This enzyme reacts very slowly at 25°C but much more quickly at 30°C, so females hatch out of eggs that are incubated at warmer temperatures. Which seems simple, except that in some species the females hatch out of the cooler eggs, and in others, males only hatch from eggs in a middle range of temperatures. **LV**

The sex of many turtle species is determined by the temperature at which the eggs are incubated





Embryonic stem cells can play the part of any cell at a moment's notice



How do stem cells turn into specific types of cells?

Q Stem cells are the ultimate substitutes in the processes of life, able to step in and play the part of specialist cells at a moment's notice. Embryos are full of all-purpose 'pluripotent' stem cells, but we all maintain a population of adult stem cells, whose more limited repertoire is used for repairing damage. Exactly how stem cells do all this is still being worked out. What is known is that they congregate in so-called niches, exposed to proteins that

communicate the condition of tissue around them. At key stages in the development of the embryo, or following disease or injury in adult organisms, these proteins activate the stem cells, switching on the appropriate genes for the specific role they're required to play. Once their mission has been completed – for example, by providing fresh skin cells to repair a wound – the stem cell niche goes back to its monitoring role, awaiting the next call to action. **RM**



Are there alternatives to road salt?



'Cheesing' the roads just doesn't have the same ring to it...

A Salt is an effective de-icer because sodium chloride lowers the freezing point of water and it's fairly cheap. But it's also corrosive and harms plant and aquatic life. In the US, local authorities have experimented with lots of other substances. Sugar beet juice, cheese brine, pig urine and calcium magnesium acetate made from fermented grass work well, but scaling up production to replace the 2 million tonnes of road salt the UK uses every year wouldn't be easy. **LV**



How do electric showers heat water so quickly?

A Inside the shower unit, cold water from your mains supply flows into a small plastic tank. Inside the tank is a heating element similar to the one found in a kettle, but four times more powerful at around 11kW. The water heats up almost instantly because only enough to maintain the flow is warmed at a time. There is also a safety cut-out should the water pressure fall too low. **GM**

TOP TEN

CIVILIAN AIRCRAFT

(BY MAXIMUM TAKE-OFF WEIGHT, MTOW)

1. Antonov An-225

MTOW: 640 tonnes
First flight: 21 December 1988
Country of origin: Soviet Union/Ukraine

2. Airbus A380-800

MTOW: 590 tonnes
First flight: 27 April 2005
Country of origin: Multinational

3. Boeing 747-8

MTOW: 442 tonnes
First flight: 8 February 2010
Country of origin: USA

4. Antonov An-124

MTOW: 405 tonnes
First flight: 26 December 1982
Country of origin: Soviet Union

5. Boeing 747-400

MTOW: 397 tonnes
First flight: 29 April 1988
Country of origin: USA

6. Airbus A340-600

MTOW: 380 tonnes
First flight: 23 April 2001
Country of origin: Multinational

7. Boeing 777-300

MTOW: 299 tonnes
First flight: 16 October 1997
Country of origin: USA

8. McDonnell Douglas MD-11

MTOW: 273 tonnes
First flight: 10 January 1990
Country of origin: USA

9. Airbus A350

MTOW: 272 tonnes
First flight: 14 June 2013
Country of origin: Multinational

10. Ilyushin Il-96

MTOW: 270 tonnes
First flight: 28 September 1988
Country of origin: Soviet Union

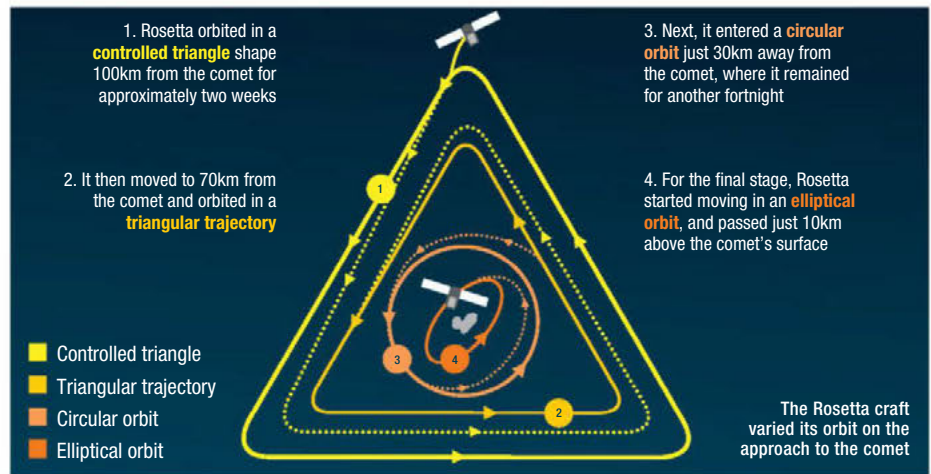
Q

How does Rosetta stay in orbit?

The Rosetta spacecraft is orbiting a very small object in astronomical terms. Comet 67P/Churyumov-Gerasimenko is only 4km in diameter and is irregularly shaped. This means the gravitational field of the comet is both small and irregular itself. To stay in orbit, Rosetta had to approach the comet gingerly. Every few days it fired its thrusters to turn it slightly towards the comet, effectively tracing out a smooth-cornered triangular trajectory around the comet. The effect of

each burn was assessed to determine the extent and direction of the next burn and to help ascertain a more accurate value for the comet's mass and gravitational field.

As time went on, these burns became more predictable and the orbit was lowered to an elliptical shape that passed only 10km above the surface. Rosetta's orbit is called a 'forced' orbit because it is 'powered' and isn't solely dependent on the comet's gravitational field. **AG**





Although this artwork shows a black hole, astronomers can't actually see them

How do astronomers estimate how many solar masses a black hole has?

A Astronomers can't see a black hole directly, but they can study the stars that are orbiting around it. By carefully measuring the speed and the radius of these stars' orbits, the astronomers can then use the laws of gravity to deduce the mass of the black hole.

This technique has been applied to stars in orbit around the black hole at the centre of our Milky Way galaxy. It showed the black hole to be about three million times as massive as the Sun.

By averaging the speeds of all the stars orbiting the central black hole in the Andromeda spiral galaxy (our nearest large galactic neighbour), astronomers deduced that it has a mass of about 30 million of our Suns.

Another technique uses a mathematical model of how material spirals into a black hole. By comparing observations of the energy emitted by this material to the model, astronomers can estimate the mass of the black hole. **AG**

Q

Why don't vultures get food poisoning from eating rotten meat?

A The acid in a vulture's stomach is almost 10 times as concentrated as ours. This destroys bacteria so efficiently that vulture droppings are actually more hygienic than the meat they eat! Vultures play an important role in the environment, by reducing the number of contagious bacteria such as botulism, hog cholera and anthrax. But a strong stomach isn't enough by itself, because once bacteria have multiplied in a decaying carcass, they release chemical toxins that aren't destroyed by acid. To counter this, vultures absorb the toxins directly through the lining of their throat and then neutralise them using antibodies present in their blood. **LV**



Yum. Delicious rotten carcass for tea!

Q

Why hasn't evolution sorted out eye defects?

A Vision defects such as myopia (short-sightedness) aren't caused by just one single gene. There's some evidence that short-sighted people have a higher than average IQ, which may be because the same genes affect the eyes and brain. Vision defects often have environmental causes as well. Myopia is more common in people who do a lot of close-up work, have saturated fat in their diet and sleep with a light on. These are all relatively new in our evolutionary history. **LV**



Superman's disguise would be rubbish if no-one wore glasses



"Woe is me! Now I'm a millionaire, I no longer enjoy watching the telly"

Can money bring you happiness?

A No. In fact, a 2014 study at the University of California, Berkeley found that being very rich or very poor were both associated with higher levels of mental illness. This doesn't necessarily mean that money (or the lack of it) drives you mad. The study found that those at risk of bipolar disorder and narcissistic personality disorder tended to be more proud of their achievements and more determined to pursue power at the expense of personal relationships. These are people who are more likely to make a lot of money, but if their personality disorder gets the better of them, they can also end up unemployed or bankrupt. Several studies have also looked at the long-term happiness of lottery winners and found that it didn't improve much. Sudden wealth can actually prevent you from enjoying the simple things you used to, like hearing a good joke or watching TV. **LV**

In Numbers

1,013

confirmed exoplanets have been discovered by NASA's Kepler Space Telescope, as of January 2015



Has the population boom affected our evolution rate?

Is the rate of human evolution increasing with population growth?

A Larger populations create more chances for genetic mutations to occur, and this means more variations for natural selection to either favour or weed out. But in big populations, it takes longer for changes to spread. The fastest rate of evolution occurs when a population is split into isolated subgroups that can't interbreed due to geographic or cultural barriers. Travel and communication have

broken down many barriers, so our genes get blended together instead of splitting into subspecies. A 2007 study found that we are evolving about 100 times faster than at any other period in our history. But 'modern' for an evolutionary biologist means the last 5,000 years. It's too soon to tell how our evolution has been affected by the population explosion of the last few centuries. **LV**



HOW IT WORKS

Range-R Wall-Penetrating Radar

When police officers pursue suspects to a building, they have no way of knowing what awaits them inside – the suspects could be hiding under the bed or waiting behind the door with a drawn gun.

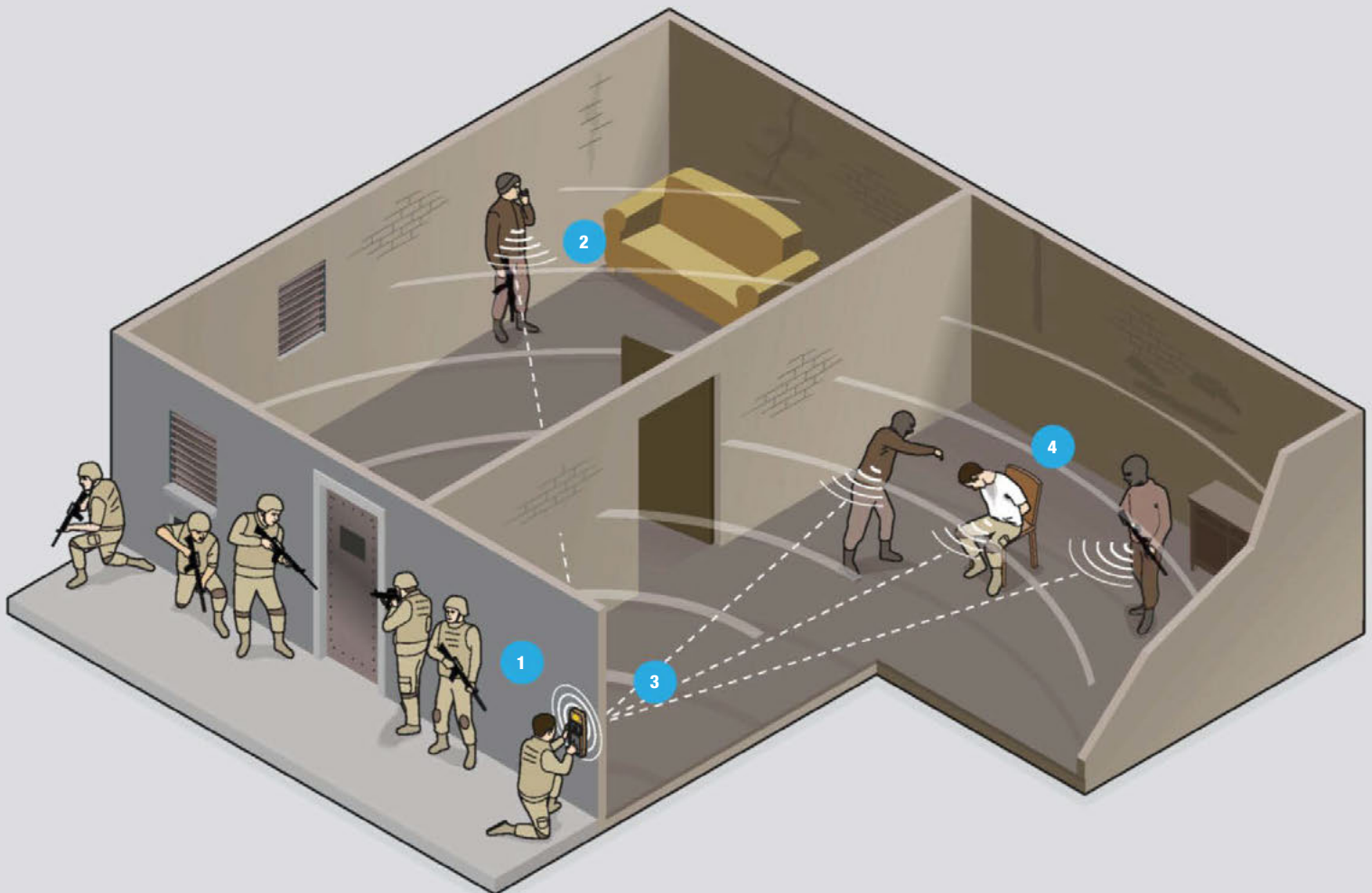
The company L-3 Communications tackles this problem with a device called the Range-R, which is a handheld radar scanner that can peek through walls and report the position of anything moving located inside. When held against a building, the Range-R emits powerful radar

pulses. These can pass through walls made of concrete, brick or wood, but not metal. Obstacles inside the building reflect the waves of radar pulses, which then return back to the Range-R.

Moving 'objects' change the wavelengths of these radio waves, enabling the device to distinguish people from furniture and other items. The Range-R's sensor is so precise that it even detects someone who is merely breathing, from up to 15m away. The device's field of view

covers 160 degrees, allowing it to scan both floors of a two-storey house in seconds. It is also a useful piece of kit for firefighters or search and rescue workers, allowing them to safely check buildings for trapped people.

US authorities like the FBI and the US Marshals have been using the scanner for the past two years, but this has come to light only recently. So far, the US Marshals have spent US\$180,000 on the Range-Rs, with each device costing US\$6,000.



1 The lightweight Range-R is held against the wall of a building. It emits radar pulses that can pass through most materials.

2 The pulses will be reflected by all people and objects in the building. They are analysed as Doppler radar returns.

3 Within seconds, the Range-R device notifies the user of any people present, and can even detect their locations.

4 Even if an individual is not moving, they can still be 'seen'. The Range-R can detect someone who is merely breathing.

Does time exist in space?

A Time is a complex subject for physics. Einstein showed that time and space are intimately linked and that the progression of time is relative, not absolute. Although there is nothing in physics that says time must flow in a certain direction, scientists generally agree that time is a very real property of the Universe. Our science is thus based on the assumption that the laws of physics, and the passage of time, exist throughout the Universe. **AG**



No matter where you are in the Universe, time still exists

At what height does a building become a skyscraper?

A There is no specific height at which a tall building is classified as a skyscraper. For most engineers, the definition is a tower block of 'considerable height' that has multiple storeys. Structurally, the walls should not be load-bearing but instead hung on a framework of steel girders and usually a central spine. **GM**



Could life have originated deep inside Earth?

A The idea that life could thrive deep below Earth's surface was once regarded as heretical. Lacking any obvious source of energy, such as sunlight, and subjected to intense heat



and pressure, subterranean organisms would seem to have little chance of survival. Yet since the 1980s, bacteria, fungi and worm-like creatures have been found lurking kilometres down in mine boreholes and deep sea sediments.

These organisms have extraordinary sources of energy. For example, some bacteria rely on the reactions between water and rocks to get their energy.

Dating techniques suggest bacteria have existed at depths of several kilometres for at least 30 million years. What isn't clear is where they fit in to the history of life on Earth: were they washed down, or are they progenitors of life on the surface? Either way, their existence has boosted hopes for life on Mars. While none has been found on the surface, NASA's Curiosity rover recently detected methane coming from within the planet – which may be the result of subterranean organisms. **RM**



What makes some drunk people argumentative and troublesome?

A It's down to the effect of alcohol on the brain. The prefrontal cortex is important for planning actions, setting priorities and inhibiting impulsive behaviour. Alcohol interferes with this, so people exert poorer judgment and worry less about the effects of their actions. They misinterpret people's intentions and easily lose control of their anger. The variable effects of alcohol on the heartbeat can also be misinterpreted as a danger signal, leading to more anger.

Low levels of serotonin and higher levels of dopamine are also associated with alcohol-induced violence – but not everyone is affected this way. Most at risk are those with poor anger control and little empathy. Expectation and upbringing are important. Adversity in early life can decrease serotonin levels, and drinking when young can damage the brain's frontal lobes. People who see alcohol-fuelled violence as children are more likely to become argumentative and violent when drunk. **SB**

Is it coincidental that the human menstrual cycle is about the same length as the Moon cycle?

A Charles Darwin thought that the 28-day human menstrual cycle was evidence that our ancestors lived on the seashore and needed to synchronise with the tides. The Moon's phase certainly has an effect on the behaviour of many animals. Fiddler crabs are more active at full and new Moons because the tides are higher, so their burrows are uncovered for longer. Gerbils avoid foraging at night during a full Moon, because the extra light makes them more likely to be eaten by owls. But the human menstrual cycle is only the same *length* as the lunar month – it isn't synchronised with a particular phase. One frequently cited study, published in the *American Journal Of Obstetrics And Gynecology* in 1980, found

some evidence of synchronisation, but the effect was very weak. Of the sample of 312 women, 244 had cycles that were longer than 29 days or shorter than 27, and only 70 per cent of the rest actually started their period within two weeks of the full Moon.

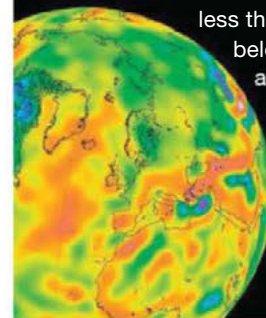
If locking our reproductive cycle to the lunar month was advantageous, you might expect other animals to do the same. Orangutans and possums have 28-day cycles, but our closest relatives, the chimpanzees, have 35-day cycles. Non-primate mammals have an oestrous cycle, which works differently to menstruation, but none of them synchronise their reproduction with the phases of the Moon. **LV**



Does gravity vary across the surface of the Earth?

A As a rule of thumb, places near the Earth's equator experience lower gravity than those near the poles, through the joint effect of the Earth's spin and equatorial bulge.

Observations by satellites show that gravity is weakest in the Peruvian mountains. But at less than 1 per cent below the global average, you'd never be able to tell. **RM**



Purple is where gravity is lowest, moving to blue, green, yellow, red and white (highest)

How does the brain distinguish between good and bad smells?

A Molecules in the air dissolve in mucus inside the nose and are detected by olfactory receptors, which send signals to the brain. In primates, including us, there are two pathways. One goes to the olfactory cortex. The other passes to the hypothalamus, which is involved with emotion, motivation and memory. This part is responsible for whether we like or reject a smell. It may also be why smells and memory have a close association.

Although humans have a comparatively weak sense of smell, it is still important. Day-old babies show expressions of disgust when they smell fish or rotten eggs. Children can distinguish between the smell of their siblings and other children of the same age. A baby recognises its mum's smell and a mother recognises their baby's. Even the

humble fruit fly has complex olfactory processing. It has *one system* that identifies a smell and another that categorises smells as good or bad. To watch the *Focus* team sampling some of the world's worst smelling foods, visit <http://youtu.be/0rwB2Cw-Pe8> **SB**

"C'mon, give it a try – it's lovely!"



Does nasal hair have any useful function?

A Certainly! It's a filter for dust, pollen, spores, viruses and bacteria. Particles stick to the wet surface of your nose hairs, which prevents them from reaching your lungs and causing infection. Eventually you'll either blow the nasties into a tissue, or swallow them, to be destroyed in your stomach. **LV**



YOUR QUESTIONS ANSWERED

A Email to editorial-bbcknowledge@regentmedia.sg. We're sorry, but we cannot reply to questions individually.

B Hardback **P** Paperback

The Village Effect

Why Face-To-Face Contact Matters

Susan Pinker

Atlantic Books **P**

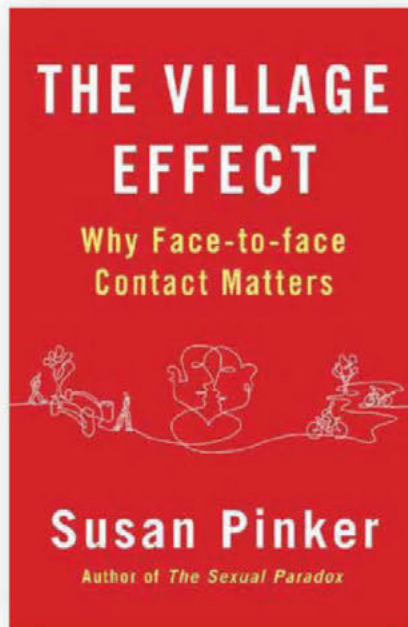
On Twitter, I have nearly 13,000 followers. Yet in the 'real world', how many people could I truly turn to? A handful, at most. I might have been a case study in Susan Pinker's new book. She describes how we're digitally interconnected on an unprecedented scale, and yet we're more lonely and isolated than ever.

This is bad for our health. Pinker cites one 12-year study of thousands of nurses who'd been diagnosed with cancer. Those who felt socially isolated were 66 per cent more likely to die during the investigation. Or consider a meta-analysis of 148 studies collectively involving over 309,000 people. It found that those integrated into their communities had half the risk of dying. Indeed, epidemiology finds real-world contact to be vital for long life.

Pinker repeatedly says that digital contact doesn't afford the same psychological benefits as in-the-flesh relationships. She takes us to a Sardinian hilltop village that boasts an abundance of centenarians – a place where everyone knows each other and multiple family generations live under one roof. Physical proximity, touch, trust, gossip and a powerful sense of belonging: these are the villagers' secrets to long life and happiness, explains Pinker.

"I think we know intuitively the value of face-to-face contact. But the digital world is here to stay"

PHOTO: SUSIE LOWE



We also hear about the limitations of online dating (their algorithms don't work, says Pinker), the financial scams orchestrated by trusted friends (the 'dark side' of face-to-face psychology), and the misguided programmes that have delivered laptops to developing nations, where investment in better teachers would have been more effective.

I winced a few times at Pinker's treatment of neuroscience, especially her simplistic caricature of the 'cuddle hormone' oxytocin and mirror neurones. More troubling is the book's bias. Pinker omits or dismisses important findings, such as a 2013 study that found moderate internet use by youths was correlated with more participation in sports and clubs; or another that found feelings of Facebook connectedness were associated with 'lower depression and anxiety and greater satisfaction with life'.

I think we know intuitively the value of face-to-face contact. But the digital world is here to stay. For me, then, what's important is how to leverage our new digital tools to foster and cultivate real, meaningful relationships. On this point, I wish Pinker had more to say.

CHRISTIAN JARRETT is a psychology writer. His latest book is *Great Myths Of The Brain*

MEET THE AUTHOR



Susan Pinker

How does communicating face-to-face benefit us compared to online?

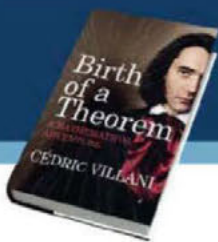
Communicating in person is not only essential for forming lasting bonds, but it also has an impact on the brain that hasn't so far been detected with electronic communication. In 2010, neuroscientist Elizabeth Redcay compared the brain activity of people who were interacting in person versus those who were watching a video of a very similar interaction. When the social partner was in the room, there was much greater blood flow to brain areas associated with social cognition, perception, attention and reward.

Lots of people find it easier to make friends online – can't social media be a useful tool in this case?

Within limits. For people who find it very difficult to communicate face-to-face, such as those on the autistic spectrum, interpersonal contact is a skill they have to learn and practise. Friends they make online don't necessarily translate into offline friendships. You can have a friend on Facebook and feel closer to them by sharing information, but you may not be getting the benefits of an intimate bond.

What would be your three tips for living in this digital age?

First, try to build a village effect into your daily life. If you're moving to a new area, look for one where people chat to each other in public spaces. Second, if you're a parent, limit your children's screentime – their brains are built for interacting face-to-face. Third, get up and talk to your colleagues. The teams who communicate in person are more productive, cohesive and loyal than those who mainly communicate through digital media.



Birth Of A Theorem

A Mathematical Adventure

Cédric Villani

Bodley Head 

In 2010 Cédric Villani won the Fields Medal, the mathematical equivalent of a Nobel Prize. *Birth Of A Theorem* describes how his prize-winning research took shape over the preceding two years. This is no popular science book – even readers with maths degrees will struggle with Villani's terminology and equations. Rather, it is an undiluted account of life as a mathematician. The main story focuses on Villani's pursuit of his elusive 'Landau damping' proof. He navigates setbacks and self-doubt, recounting moments of inspiration. The pages are scattered with excerpts, quotes and poems. It reads almost like a diary and makes for a fascinating – yet frustrating – book. There are some wonderful parts, such as when he compares algorithms that exploit randomness to the meandering in his own career path. But these are often lost among reproductions of emails and mathematical derivations. By telling the story of his quest, Villani reveals a rarely glimpsed world and shows the dedication required to reach the very top. However, by including so much unfiltered detail, the complexity of his journey will leave many readers behind.


ADAM KUCHARSKI has a doctorate degree in applied mathematics from Cambridge



Science For Life

A Manual For Better Living

Brian Clegg

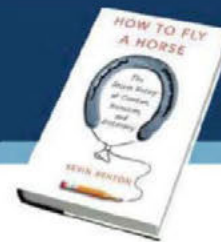
Icon Books 

Is coffee good for you, or bad? If you read the newspapers you can be forgiven for not having the foggiest idea. Every day, we're bombarded with stories contradicting what we read the previous week – about everything from climate change and brain training games, to the benefits (or not) of drinking red wine.

Brian Clegg has produced the ultimate antidote. In *Science For Life*, he has researched the evidence for and against these claims – and over 200 more. For example, did you know that saturated fat is no worse for you than unsaturated? Or that there's no evidence whatsoever for the Mozart effect? Or that a UK-grown tomato comes at three times the environmental cost of one produced in Spain, thanks to the need for heating in our chilly climate?

Science For Life is divided into various headings, with a 'Fun' section that offers a scientific slant on topics such as why buses arrive in clusters and how to get served quickest in a queue (this is a field Clegg helped to develop while working at British Airways). This handy, well-written guide is a triumph of reason over press release reporting.

PAUL PARSONS is a science writer and a statistical analyst at Botsphere



How To Fly A Horse

The Secret History Of Creation, Invention, And Discovery

Kevin Ashton

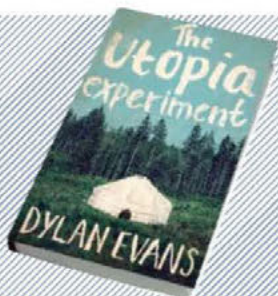
William Heinemann 

Creativity is probably the most important thing that distinguishes us from other animals. It is something that many of us dream of harnessing, but attribute it to other people. Kevin Ashton's engagingly titled new book argues against letting ourselves be intimidated. As a tech entrepreneur, co-founder of an MIT laboratory and pioneer of the 'Internet of Things', he's someone who should know.

Beginning with the tale of how Mozart's working method was reimagined by biographers keen to set him on a pedestal, the book sets out to deconstruct the myth of genius by looking at the truth behind many inventions, discoveries and works of art.

With help from a vast cast of characters ranging from Nobel laureates to Dexy's Midnight Runners, Ashton shows how, more often than not, great breakthroughs stem not from a flash of inspiration, but from the more mundane business of identifying problems, lateral thinking, trial and error, teamwork and persistence. It's an inspiring vision of creativity that's littered with practical advice, and is a cracking read to boot.

GILES SPARROW is a science writer and author. His latest book is *Mars*



The Utopia Experiment

Dylan Evans

Picador 

This is a fun read – as well as a scary one. *The Utopia Experiment* describes one man's response to the threat of imminent climate change. Dylan Evans, a psychologist turned robotics researcher, saw serious trouble ahead and set out to study how people might survive in a post-apocalyptic world. He bought land in Scotland, invited volunteers to join him, and set about trying to live without the support of modern civilisation. He and his band of yurt-living, apocalypse-ready campers attempted to apply their skills and science to building shelters (badly), growing food (ineptly) and keeping warm (or not).

Was this a serious experiment, or just a personal – and disastrous – indulgence in post-apocalyptic living? Was Evans secretly longing for the end of life as we know it? Was he lured by the heroic idea of surviving against the odds, by being among the few to cope with climate chaos? Was he drawn by an imagined escape from the troubles and stresses of modern life? Draw your own conclusion as the experiment unfolds and madness overtakes him.

SUSAN BLACKMORE is a psychologist and a visiting professor at Plymouth University

HOLLYWOOD SCIENCE

Communicating with dogs in *The Voices*

Last year, I made my dog wear a Christmas jumper. He wore it resentfully, before extricating himself from it, Houdini-style, and burying it in the garden. It's as if he was trying to tell me something. In the film, *The Voices*, man and dog go one step further. They actually talk to one another. But to what extent do we share meaningful communication with our mutts?

Some dogs clearly understand more than others. Chaser, a 10-year-old border collie, not only knows the names of over 1,000 different objects, but also seems to have a basic grasp of grammar. As well as simple two-word commands, Chaser also responds to more complex sentences.

“The world is awash with stories of Lassie-esque mutts who saved their owners”

Her genius is a result of intensive training from her retired psychologist owner, and raw talent. “There are some remarkable dogs out there,” says Juliane Kaminski from Portsmouth University’s Canine Cognition Centre. “But critics still argue how much these dogs actually understand and how much they are simply responding to previously learned associations.”

Dogs are, however, indisputably brilliant at interpreting non-verbal cues. Dogs, Kaminski has shown, intuitively ‘get it’ when a person points to a hidden treat and they use the information to retrieve the reward. To comprehend pointing, Kaminski argues, dogs must have an understanding about the perspective and knowledge of others. I knew it; my dog *does* understand me. But does he talk to me... apart from in my head?

The world is awash with stories of Lassie-esque mutts who saved their owners from peril by ‘telling’ someone they were in danger. Such claims are impossible to verify, so Kaminski is interested in whether dogs can communicate by pointing. She set up an experiment where



In *The Voices*, Jerry's cat encourages him to kill, while his dog is the good guy

a dog watched a person play with a toy, then dropped it on the floor and left the room. A stranger then entered and hid the toy, before the original person came back and started looking for it. Would the dog, who had watched the whole scenario unfold, point to or guide the person to the missing object? Man's best friend? Of course he did.

But here's the rub. Kaminski found that if the squeaky toy was replaced with something of little doggie value, such as a pair of scissors, the mutt had no interest in 'talking to us'. In this situation at least, dogs communicate with us only when there's something in it for them. Bad news if you want to discuss current affairs, but good news if you're looking for tips on how to pee on lamp posts.

HELEN PILCHER is a science writer and comedian. She tweets from @Helenpilcher1

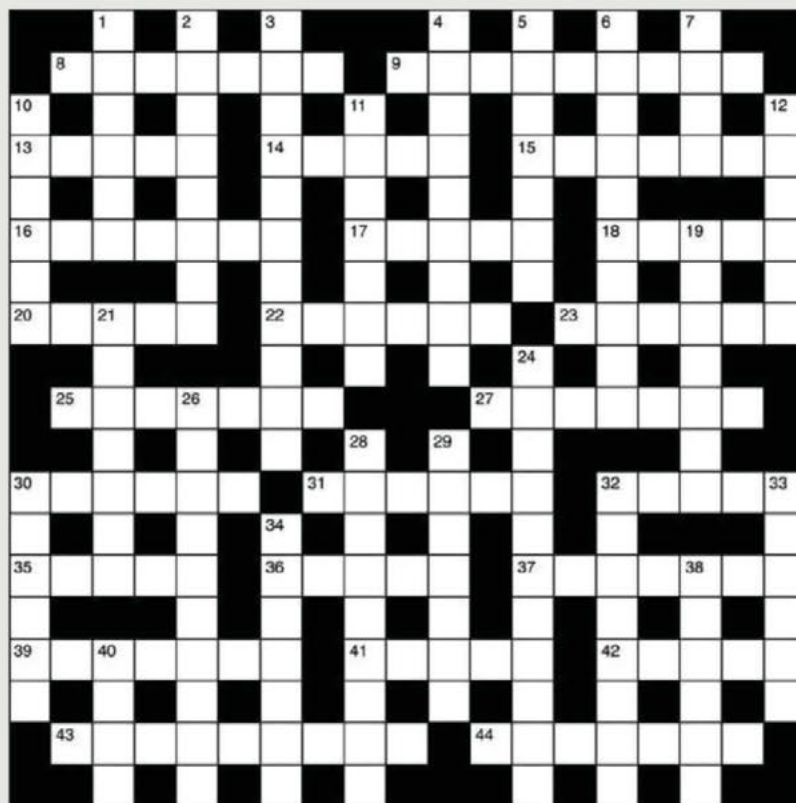
Crossword No.177

ACROSS

- 8 Neural network around old bit of seed (7)
- 9 Soldier takes middle tree to set limit (9)
- 13 A riot out of proportion (5)
- 14 Rural deity joins a group of animals (5)
- 15 Decay terribly rife in aquatic creature (7)
- 16 Mushrooms from island finally in crop rotation (7)
- 17 Old aristocrat puts one article inside another (5)
- 18 Deer flocking round one duck (5)
- 20 Attach a smidgeon around gap (5)
- 22 Rascal finds part of play leaves an impression (6)
- 23 Mark, in Germany, makes a different sound (6)
- 25 Not glib, ordering a snack (7)
- 27 Attempt to find one record among set of books (7)
- 30 Pat and Ian ran from snake (6)
- 31 Bilge written about river rodent (6)
- 32 Wager on the Spanish climber (5)
- 35 Reportedly influenced by material (5)
- 36 New aim – to leave an idealised picture (5)
- 37 Quarry contains gold and a form of debris (7)
- 39 Some light has energy – it's an inflammation (7)
- 41 Canoe unsuitable for so much water (5)
- 42 Generate small piece (5)
- 43 Roast tuna prepared for distant traveller (9)
- 44 Skull found around a ruin gets confused with my head (7)

DOWN

- 1 Overcoat of unusual lustre (6)
- 2 Rue mixing drug and element (8)
- 3 Numerical factor makes firm streamlined (11)
- 4 Almanacs delivered to a city (9)
- 5 Transmitter in a bag (7)
- 6 Set with different graduate is using our own heat (10)
- 7 Part of tree in field falls, initially (4)
- 10 Subject includes right line of latitude (6)
- 11 Secondary genre of U-boat (7)
- 12 A traitor captures artist by mountain (6)
- 19 Current doctor treats a thug (7)
- 21 Poisonous ingredient in a new range of products (7)
- 24 Use a rein primly in qualifying round (11)
- 26 Path to carry jet away (10)
- 28 Gauge demo to have been arranged by agitator (9)
- 29 Terribly bad sign from the middle (7)
- 30 It's been sneezed in, that's the matter (6)
- 32 Crooner Rod's managed inside to get a natural sound (8)
- 33 Gothic supporter writes message with hesitation (6)
- 34 Begins engagement with a tonic (7)
- 38 Doomed flier takes one vehicle to America (6)
- 40 Point a set out (4)



SOLUTION TO CROSSWORD 174



The Last Word

Why you should take studies of human behaviour with a pinch of salt

Did you see the story about how personality is the result of upbringing rather than genes? How about the one claiming that happy couples often have similar hormones, or that city living messes with sleep patterns? I love these kinds of stories – right up until I get beyond the headline and read the lame line “at least in birds”. Or in aardvarks, tadpoles or some other creature.

The feeble logic behind such stories is that the outcome of studies of animals might be relevant to humans. Well, it might – though I generally doubt it very much. In any case, the only way to tell is by doing experiments on humans, and until then I’m really not interested. Yet even my jaundiced attitude presumes that studies of humans will lead to genuine insights. Sadly, that is far from guaranteed.

Every week the media reports new research showing that, say, people are most prone to arguments in late November. Chances are that the researchers actually discovered that US students row with their parents during Thanksgiving.

Okay, I made up that scientific nugget, but the dangers of believing claims based on human studies are real enough. A few years ago, a team led by psychologist Prof Joseph Henrich of the University of British Columbia found that much of what science supposedly knows about ‘human’ nature is based on studies of a very special set of people: those from what they termed WEIRD societies (western, educated, industrialised, rich and democratic).

It’s not just where the participants hail from that’s a problem – what they’re asked to do is pretty questionable as well. In his best-selling book *Thinking, Fast and Slow*, Nobel-winning psychologist Daniel Kahneman recalls his surprise at learning that experiments on human risk-taking often involve piffling sums of money. It’s therefore unlikely that such studies will tell us much about how we make life-changing decisions.

But perhaps the biggest problem with so much human-based research is how it ignores the subtleties of behaviour. Take the case of arguably the most famous of all psychology experiments, performed by the brilliant US psychologist Stanley Milgram in the early 1960s. Milgram wanted to investigate how ordinary people from a civilised

Stanley Milgram's study suggested that even nice people can be persuaded to do nasty things



“Milgram wanted to investigate how ordinary people from a civilised society could commit acts of appalling barbarity”

society could commit acts of appalling barbarity, as Germans did under the Nazis, for instance.

He recruited people to take part in a study of memory, which involved giving an unknown person increasingly powerful shocks as punishment for mistakes. In reality, the victim was just an actor pretending to be in pain, and the study was trying to find out how to persuade people to continue to give shocks, despite the apparent agony they were inflicting. Astonishingly, almost two-thirds of the participants obeyed instructions to continue giving shocks, all the way up to apparently lethal levels.

Milgram argued that this showed nice people will commit nasty acts if they’re able to convince themselves they’ve shifted the responsibility. Yet new research suggests Milgram missed key insights by categorising people as obedient or not. Analysis of voice recordings during the experiment has revealed that the way people are instructed to continue is crucial. It turns out that simply telling people they have no choice but to continue often triggers rebellion. That’s a new and comforting insight from Milgram’s otherwise depressing study. It’s also one worth pondering whenever scientists insist we have no choice but to accept their findings.

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